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Mould tool for the primary moulding or remoulding of components made from thermally influnceable materials

Description

The invention relates to a moulding tool for original shaping moulding or transformational shaping moulding of components of thermally influencible materials according to the preamble of claim 1.

Fibre-reinforced plastics are becoming increasingly important in many fields of vehicle technology. Typical examples of long fibre-reinforced plastic constructions are add-on components for cars (e.g. spoilers), body parts with a large surface area for rail and commercial vehicles, boat hulls from small kajaks to large yachts, as well as rotors of wind turbines. In aviation and motor racing (e.g. in Formula 1), structures now largely consist of long fibre-reinforced plastics on account of their excellent weight-specific properties. A very important advantage of the fibre-reinforced plastics, besides their good weight-related mechanical properties, is the almost unlimited freedom of design as well as the possibility of being able to produce components in almost any size and also in small to medium quantities with comparatively low investment costs.

Therefore, fibre-reinforced plastics have until now preferably been used in small to medium series as well as in prototype construction. In particular long fibre-reinforced fibre-composite plastic components, which are preferably produced with thermosetting plastics, on account of the hardening times of the plastic, require long residence times in the mould, resulting in long cycle times and severely restricting the large-scale suitability of such components.

In order to increase profitability here, suitable moulds, which in particular in the case of large components usually also consist of fibre-reinforced plastic, are heated. Due to a reduction in the resin viscosity, targeted temperature control during component production supports the impregnation of the fibres and in particular significantly accelerates the hardening of the thermosetting plastics. Moreover, due to the supply of heat, the degree of cross-linking of the thermosetting plastics is increased with the result that, for high-quality components, so-called tempering is essential. This tempering is even prescribed for components which are used in aviation, depending on the plastic system utilized.

In tool making it is standard practice to heat moulds for the production of workpieces and, in the case of metal moulds, this is generally carried out as fluid heating or as electric resistance heating. In both cases the high heat conductivity of the metal mould guarantees an even, homogeneous temperature distribution in the moulding tool.

However, metal moulds are very expensive. For very large components, metal moulds are uneconomical, especially if these components are only produced in small quantities. Therefore, suitable fibre-composite components such as mentioned above are frequently produced in plastic moulds which are much more cost-effective than metal moulds and still guarantee an adequate number of demouldings. In the case of plastic moulds at least 100 demouldings per mould are usual; with a corresponding mould structure more than 1000 demouldings per mould can be achieved. By contrast, metal moulds allow a large number of demouldings without subsequent treatment of the mould, but also require correspondingly higher capital expenditure.

The heating of suitable plastic moulds is problematic, as the heat conductivity of the plastic is substantially lower than that of metals and in addition, in particular in the case of uneven heat distribution in the mould, it is very susceptible to distortion. This is problematic for components with high shape accuracy and dimensional accuracy requirements. For this reason plastic moulds that were heated with water could not be widely used. In general, for plastics-processing businesses which produce suitable components, a separate tempering room is required. After production, moulds with the components for hardening and tempering are placed in the tempering room.

In the case of metal moulds in particular it is known that moulds can be heated by means of fluids. The moulds are equipped with a fluid duct system designed in various ways, through which correspondingly tempered fluids are conveyed. The duct system heats the mould at a certain distance from the surface actually to be heated. However, in the case of mould materials with good heat conductivity this is unproblematic. In the case of mould materials with low heat conductivity, such as e.g. in the case of plastic moulds, the low heat conductivity leads to an uneven temperature distribution. Therefore plastic moulds to be correspondingly heated are provided in parts with heat-conducting fillers such as e.g. aluminium powder, in order to improve heat conductivity.

Nevertheless a relatively poor dimensional accuracy, distortion of the moulds, an uneven temperature distribution and the relatively high manufacturing costs are problematic in the case of fluid-heated plastic moulds. Due to the high masses of such moulds a relatively high energy consumption is required for each heating process.

Electrical resistance heating represents an alternative. In the case of metal moulds heating cartridges are frequently used for this. Due to the high heat conductivity of the metal mould material a sufficiently homogeneous temperature distribution is generally achieved.

With plastic moulds two-dimensional heating near the surface to be heated is advantageous, on account of the relatively poor temperature conductivity. This can be achieved by means of suitable heating fabrics which can be embedded in the plastic near the mould surface. Heating fabrics developed especially for this purpose consist partly of resistance wires or also of conductive fibre material, such as e.g. carbon fibres. The resistance wires or resistance fibres act as ohmic resistance heating elements. In fact this type of heating is a heating with linear effect, in which heat is produced along each individual resistance wire or each resistance fibre and conducted to the surrounding moulding compound. However, in the case of very fine and dense distribution of the resistance wires or resistance fibres this heating, observed macroscopically, has an approximately two-dimensional effect.

In these resistance heating processes, the heating elements acting as wires or fibres are embedded in electrically insulating layers. These electrically insulating layers can, e.g. in the case of glass-fibre-reinforced plastic moulds, consist of epoxy resin and glass fibres which are known to have very good electrical insulation, but also relatively poor heat conductivity. The insulating layers generally represent a substantially larger proportion of the cross-section and mass of the mould structure than the heating wires or heating fibres. This leads to a temperature increase at the interface with heating wire or heating fibre as well as to internal stresses on account of the different mechanical and thermal properties of heating wires or heating fibres. This is in particular also associated with a risk of distortion of the moulds.

As already mentioned above, carbon fibres (C fibres) can also be used as electrically conductive fibres. Compared with most metals, C fibres have low electrical conductivity in the fibre direction, and compared with plastics have good heat conductivity in the fibre direction. They are therefore particularly suitable as ohmic resistance fibres. Another feature is the low thermal expansion coefficient of the carbon fibres which, depending on the type of fibres, can be expressed in values of approximately $\alpha_{therm} \approx - 0.1 \cdot 10^{-6}$ / K. Therefore, carbon fibre laminates (which are layered constructions of carbon fibres embedded in a matrix which often consists of plastic) with suitable fibre orientation can be constructed in such a way that the thermal expansion of the laminates cannot be practically measured in wide temperature ranges.

Until now, plastic components or plastic moulds heated with carbon fibres have been constructed in such a way that either individual fibres, fibre bands or woven fabric or a thin carbon fibre fleece with short fibres are embedded in plastic moulds between further, electrically insulating layers. A common feature of these components or moulds is a clear separation of functions between the carbon fibres serving as resistance heating and further laminate layers which essentially form the supporting structure of the mould and as a rule also act as electrical insulation for the current-carrying carbon fibres.

From DE 10 2004 042 422 A1 a heatable moulding tool is known, in which with carbon fibres, embedded in a plastic matrix an electrical resistance heating element is used with which, however, on account of the arrangement of the resistance heating element relatively far from the surface of the component to be produced and on account of the layer thicknesses of the fibre composite layers of the moulding tool, high heating powers are required in order to sufficiently temper the component. Also, on account of the series connection of the individual carbon fibre elements, electrical reliability is not guaranteed on account of possible short circuits and thus also sporadic heating failures.

Until now, the construction of the heating layer with individual fibres or fibre bands has generally involved individual or several parallel fibres or fibre bands being placed on the surface to be heated, in the form of strands. The individual strands are then connected in series, wherein in each case two adjacent strands are connected to form a total of 4 serial strands. Suitable dimensioning and circuitry has been described e.g. by the company R&G Flüssigkunststoffe of Waldenbuch in the brochure “Heizsystem für Kunstharzformen” [Heating system for synthetic resin moulds]. The company’s publication shows, with reference to an example, how a total of 8 strands, each individual one of which consists of 4 adjacent carbon fibres, are connected in series.

This procedure gives rise to substantial disadvantages, in particular when strands are connected in series, as greater potential differences occur between two touching fibre strands. This repeatedly leads to short circuits in the mould, which can be caused by individual carbon filaments of fibre strands touching. This problem occurs in particular in the case of a meandering arrangement of the heating elements. This can be avoided by a sufficiently great safety distance between touching carbon fibre strands. However, wider “unheated regions” then occur at the same time, which in turn results in an uneven temperature distribution.

A further disadvantage lies in the different mechanical and thermal properties of the further laminate layers forming the electrical insulation of the heating layer and moreover substantially forming the supporting structure of the mould. These mostly consist of glass-fibre-reinforced plastic. The different thermal expansions of glass-fibre-reinforced plastic and carbon fibre-reinforced plastic give rise to significant thermal stresses and distortions in the case of corresponding temperature differences. These can generally only be controlled, but not completely avoided, by high wall thicknesses of the mould construction. Sandwich-construction of plastic moulds is also a known approach, with which distortion can be reduced, but not completely avoided under the abovementioned preconditions.

From FR 2 691 400 A1 and EP 0 218 038 A1 moulding tools are known, in which uni-directionally formed arrangements of carbon fibres are introduced into a plastic matrix near the surface as heating elements, and serve to heat workpieces to be produced. The document EP 0218038 A1 discloses a moulding tool according to the preamble of claim 1.

The object of the present invention is therefore to avoid the described problems during the heating of moulding tools and to ensure, with a suitable construction of the layers of the moulding tool, that the heating of moulding tools can be carried out safely and in an energy-efficient manner.

The solution to the object of the invention can be achieved on the basis of the characterising features of claim 1 in conjunction with the features of the preamble. Further advantageous versions of the invention emerge from the dependent claims.

The invention relates to a moulding tool for original shaping moulding or transformational shaping moulding of components of thermally influencible materials, preferably plastics and in particular fibre composite materials, in which the moulding tool has a fibre composite structure and an electrical resistance heating element, wherein carbon fibres or carbon filaments are embedded in a plastic matrix in the fibre composite structure of the moulding tool near the shaping surface of the moulding tool. Such a generic moulding tool is further developed in that the carbon fibres or carbon filaments in the plastic matrix near the shaping surface determine substantially the mechanical properties, in particular strength, rigidity and/or thermal expansion of the shaping tool and the electrical resistance heating element is so connected that at least individual portions of the electrical resistance heating element form an electrical parallel circuit with each other. The special feature of the invention lies in the integration of the heating layer and the structure of the mould surface. It is important that the carbon fibre layers are used as resistance heating element and at the same time form the main component of the cross-section of the mould surface. It is not the proportion of the layer thickness of the carbon fibre layers compared with further layers that is decisive, but the fact that the carbon fibre layers dominate the mechanical properties, in particular the strength, the rigidity and also the thermal expansion of the layer construction of the fibre composite structure. With the help of the invention the mass of corresponding moulding tools can be clearly reduced, which clearly reduces the overall thermal capacity of the moulding tools and thus the energy consumption during heating of the moulding tools. Due to the construction according to the invention and a co-ordinated material selection heat distortion of the moulds can largely be avoided in a wide temperature range. With the invention a cost-effective solution has been found, allowing moulding tools of almost any size to be electrically heated homogeneously and with comparatively low energy consumption. The main point of the invention is the integration of heating layer and supporting cover layer, wherein the electrical conductivity of carbon fibres is utilized in order to use the supporting cover layer of the mould directly as resistance heating. In contrast to previous attempts to use the electrical conductivity of carbon fibres as resistance heating, the electrical connection system of the moulds is in the form of a parallel circuit so as to rule out short circuits such as in the case of the customary series circuit due to potential differences between heating strands touching one another. This also allows further insulating layers, with the exception of the mould cover layer, to be dispensed with as far as possible. Due to the parallel circuit of the electrical resistance heating element the resistance of the electrical resistance heating element is greatly reduced and thus the moulding tool can already be heated with low voltages to be applied.

Whereas unidirectional carbon fibre woven fabrics or non-woven carbon fibre fabrics have preferably been used in existing carbon fibre-based heating layers, bi-directional carbon fibre woven fabrics are preferably used here. The use of multi-axial woven fabrics or non-woven fabrics is also conceivable. In the present case, carbon fibres running crosswise ensure potential equalization orthogonally to the current flow in the heating layer. Defects or interruptions in individual carbon fibres can also be bridged over in this way. The electrically directly contacted carbon fibres can preferably run parallel in the longitudinal direction of the moulding tool and additional carbon fibres, running crosswise or diagonally to it, can also assume a conducting function indirectly via the layer contact and can in this way, on the one hand, bring about an electrical potential equalization crosswise to the main current flow direction and, on the other hand, allow a multi-axial, preferably quasi-isotropic laminate construction which, with the use of carbon fibres, allows the construction of cover layers with very low thermal expansion.

The arrangement of carbon fibres or carbon filaments that forms the electrical resistance heating element are partially or entirely units in the form of non-woven fabrics, woven fabrics or fleece materials. Individual portions of the component-side surface of the moulding tool can be formed with such units over the entire surface or also only over portions, which are then again interconnected overall in the form of a parallel circuit. It is advantageous that, in addition to the adaptation of the mould and formation of such units to the respective topography of the component, a largely two-dimensional heating of the component is achieved, which can only be achieved at great expense in the case of customary meandering series-connected resistance heating elements.

It is particularly advantageous that the carbon fibres or carbon filaments are incorporated in the plastic matrix in directly adjoining relationship with the component-side surface of the moulding tool. The heating of the moulding tool integrated in this manner produces the heating power directly on the component-side mould surface. The heating takes effect extensively directly where the heat is required. This shortens the heat flow paths, reduces excess temperatures in the immediate surroundings of the carbon fibres and leads to a very energy-efficient conversion of the electrical heat energy.

In a further development it is conceivable that the arrangement of carbon fibres or carbon filaments that form the electrical resistance heating element or units formed from same are substantially of a quasi-isotropic nature. It can thus be achieved that with regard to both the mechanical strength values and the thermal effect of the carbon fibres or carbon filaments or units formed from same, the same conditions are present in all regions of the moulding tool and a uniform tempering of the component to be produced is thus achieved over all regions of the component.

A further embodiment is designed such that, in part, either additional carbon fibre layers are applied or also the number and/or thickness of the carbon fibre layers is reduced. The important feature is that due to the ohmic behaviour of the mould the surface heating power is partly changed. In this way different surface heating powers can also be equalised, which inevitably occur for example with non-rectangular mould cross-sections. Thus for example in the case of an elongated, trapezoidal mould with clear tapering, the overall thickness of the carbon fibre layers would have to increase continuously towards the tapering end if a constant surface heating power is to be achieved over the entire mould surface.

It is also conceivable that electrically non-conducting regions are provided between individual units of the arrangement of carbon fibres or carbon filaments that forms the electrical resistance heating element. Such non-conducting regions can serve the targeted temperature formation in the component, as in such non-conducting regions there is also no active tempering of the component and targeted temperature gradients can thus be achieved within the component when it hardens. It is conceivable that the electrically non-conducting regions are inserted within a plane or perpendicularly between mutually superposed planes, in order to separate the respective adjacent or mutually superposed resistance heating elements from each other.

With respect to the mechanical behaviour of the moulding tool it is of particular importance that the arrangement of carbon fibres or carbon filaments that forms the electrical resistance heating element or units formed from same in the plastic matrix has a high rigidity. As the other layers can at the same time be made less rigid, the overall rigidity of the moulding tool is thus predominantly determined by carbon fibre layers. Moreover, thermal stresses between different materials in approximately equally rigid layers of the moulding tool can thus be avoided, decisively reducing the distortion of the moulding tool on heating, whereby the dimensional accuracy of the component to be produced can be clearly increased.

With respect to the stresses and distortions occurring during the tempering of the moulding tool, it is important that the thermal expansion of the layer of carbon fibres or carbon filaments including the electrical resistance heating element or units formed from same in the plastic matrix is very small. Even in the case of larger changes in the temperature of the moulding tool this is accompanied by only a small dimensional change of the component to be produced, whereby production is simplified and improved. During use of the moulding tool the cycle times can be further reduced by active cooling, which can be achieved simply in that, when the moulding tool is constructed in sandwich form, the core of the sandwich has passages passing through it, through which cooling air or other gaseous or liquid cooling media are passed. It is also possible to pass corresponding media through the mould in a closed circuit during the heating phase, to equalize temperature gradients. A suitable mould capable of drainage can be constructed simply e.g. with slit core materials.

A further improvement in the profitability of the use of moulding tools formed according to the invention can be achieved as the energy consumption for heating the moulding tool is also only low on account of the small layer thicknesses of the material of the layer including the electrical resistance heating element. The tempering and cooling of the mass of the moulding tool can take place substantially faster and with lower energy consumption on account of the small layer thicknesses with the result that the cycle times for producing corresponding components can be reduced.

Furthermore it is advantageous that the electrical resistance of the carbon fibres or carbon filaments connected parallel with each other or units formed from same is very low overall due to the parallel circuit. It is thus possible that even low voltages, in particular low voltages for heating, can be used on the electrical resistance heating element, thus also guaranteeing electrical reliability and minimizing energy consumption.

With respect to the formation of the surface of the component to be produced it is advantageous if the component-side surface of the moulding tool is formed by a mould cover layer, which covers the layer including the electrical resistance heating element on the component side, preferably in a thin layer. A thin mould cover layer of this kind ensures smooth surfaces of the component and avoids damage to the layer including the carbon fibres. Due to correspondingly small layer thicknesses and good heat conductivities of this mould cover layer, problems with the thermal conductivity between the layer with the resistance heating element and the component, which could otherwise arise, are safely avoided.

With respect to the mechanical stability of the moulding tool it is advantageous if a reinforcing layer is applied on the side, facing away from the component, of the layer including the electrical resistance heating element. A reinforcing layer of this kind, which e.g. can be formed as a stable light-weight construction layer for instance of a sandwich structure, ensures further mechanical fixing in the construction of the moulding tool, without excessively increasing the weight of the moulding tool. In the case of a sandwich structure the heating layer can preferably at the same time produce one of the two cover layers which are required for the construction of a sandwich structure. It is for example also conceivable that the reinforcing layer is formed electrically insulating.

With respect to the construction of the layers of the moulding tool it can be advantageous if additional intermediate layers are arranged between the fibre composite layer including the electrical resistance heating element, the mould cover layer and/or the reinforcing layer, which e.g. are formed electrically insulating or have an adhesion-enhancing function for the adjacent layers of the fibre composite structure. Intermediate layers of this kind which can be formed for instance from a preferably thin glass fibre woven fabric in the fibre composite structure optimize the properties of the layer structure overall.

It is furthermore conceivable that a layer with carbon fibres which are incorporated in a plastic matrix can be provided as the further mould cover layer arranged on the side of the reinforcing layer facing away from the component. A distortion of the layers of the moulding tool during tempering is thus further prevented, as this further mould cover layer can be constructed mechanically similar to the fibre composite layer including the electrical resistance heating element and thus for instance a reinforcing layer arranged between them is surrounded on both sides by mechanically equivalent layers. It is conceivable that the carbon fibres of the mould cover layer facing away from the component are electrically insulated from the carbon fibres of the fibre composite layer which faces the component and which includes the electrical resistance heating element.

With respect to the uniform mechanical and electrical properties of the fibre composite layer including the electrical resistance heating element it is advantageous if the orientation of carbon fibres or carbon filaments or of the units of carbon fibres or carbon filaments is displaced and/or rotated with respect to other carbon fibres or carbon filaments or the units of the same fibre composite layer. The fibres or units could thereby be orientated so that mechanical loads and also temperature production are largely uniform within the fibre composite layer including the electrical resistance heating element and are thus also correspondingly uniformly transmitted to the component.

It is furthermore advantageous if the mould cover layer and the intermediate layers have only low rigidity and only slightly influence the mechanical properties of the fibre composite structure overall. This does not produce any substantial stresses between the individual layers during tempering of the moulding tool, so that distortions of the moulding tool are minimized.

With respect to the electrical contacting of the electrical resistance heating element it is advantageous if the arrangement of carbon fibres or carbon filaments that forms the electrical resistance heating element or units formed from same are, at the end of the fibres or units, electrically contacted and connected together in the form of a parallel circuit. Due to the external contacting it is possible to achieve good accessibility of the resistance heating element and the wiring work for the parallel circuit can be carried out simply.

With respect to the tempering of the component, it has in particular proved particularly advantageous for the required energy consumption if, during the heating of the moulding tool for shaping a component, the moulding tool is encased in thermal insulation, at least in sections. Due to the thermally insulating casing the heat produced can be retained particularly well within the moulding tool and, depending on the presence of insulating material, the nature and thickness of the insulating material as well as the positioning of the insulating material, the insulating material can be used for local temperature control during the heating of the component within the moulding tool. Thus it is for example conceivable to insulate the moulding tool only locally and thus to produce locally higher temperatures which influence the hardening of the component differently to non-insulated or less insulated regions. This allows further influencing of the production process of the component within the moulding tool.

It is particularly advantageous if the materials of the moulding tool are designed for temperatures such that the layers of the fibre composite structure that form the moulding tool withstand a temperature during production of the component of up to 300°C, preferably of up to 140°C without problems, without even compromising strength properties. In a further development relating to the temperature stability it is also conceivable that ceramic matrix materials are used to form the fibre composite structure or parts thereof.

It is furthermore conceivable that the electrical heating elements are segmented in the current flow direction and individual segments can be entirely or partially bridged over by additional electronic components in order to influence the current flow and the heating power in the corresponding segment. This allows thermal energy to be introduced there in quite targeted manner into the components to be processed in which the thermal energy is required, whereas in other regions no, or less, thermal energy is produced in the electrical heating elements. It can be advantageous here if the electrical heating elements are segmented in the current flow direction and the individual segments of a heating element form a series circuit. It can thus in particular be achieved that the segmented electrical heating elements can be operated overall with low voltage due to the series circuit even in the case of large dimensions of the moulding tool and thus a simple heating of the moulding tool can be achieved both electrically and also in terms of safety.

Furthermore it is conceivable that individual current-carrying mutually superposed layers of the electrical heating elements are insulated from each other in the thickness direction by thin insulating layers in such a way that an individual segment division can be achieved by stacking thin-layer heating elements using multi-layer technology. In this case a varying contribution of thermal energy achievable with the segmented construction of the heating elements is achieved by stacking heating elements arranged substantially perpendicular to the moulding tool surface, which are in each case stacked electrically separated from each other by thin insulating layers.

In a further development the current flow in the moulding tool can be locally changed by introducing additional thin and locally limited electrical heating elements in such a way that a partial change in the surface heating power within the surface of the moulding tool is possible. All the abovementioned measures can ensure that a locally effective change in the contribution of thermal energy into the surface of the moulding tool is achieved, which is advantageous for example for the original shaping or the transformational shaping of the component at this local position.

A particularly preferred embodiment of the moulding tool according to the invention according to claim 1 is shown in the drawing.

There are shown in:

Fig. 1 - construction of a simple heatable moulding tool according to the invention in rectangular form, shown using the example of a partial cross-section,

Fig. 2 - current, heating power and surface heating power of the mould in the case of predetermined heating voltage of the moulding tool according to Figure 1,

Fig. 3 - temperature curves for the heating of the moulding tool according to Figure 1 with different insulations for a surface heating power of 200 W/m^2.

As an example, Figure 1 shows the construction of a simple heatable moulding tool in rectangular form, in which the moulding tool can be produced with the following layer construction:

1st layer: Mould cover layer (layer thickness $s_1 \approx 0.4$ mm)
2nd layer: Glass fibre woven fabric 105 g/m^2 (layer thickness $s_2 \approx 0.1$ mm)
3rd layer: Biaxial carbon fibre woven fabric 193 g/m^2 (layer thickness $s_3 \approx 0.27$ mm), fibre orientation 0° / 90°
4th layer: Biaxial carbon fibre woven fabric 193 g/m^2 (layer thickness $s_4 \approx 0.27$ mm), fibre orientation ±45
5th layer: Glass fibre woven fabric 105 g/m^2 (layer thickness $s_5 \approx 0.1$ mm)
6th layer: Polyamide honeycomb core ECA 3.2-48 (layer thickness $s_6 \approx 12.7$ mm)
7th layer: Biaxial carbon fibre woven fabric 193 g/m^2 (layer thickness $s_7 \approx 0.27$ mm), fibre orientation ±45
8th layer: Biaxial carbon fibre woven fabric 193 g/m^2 (layer thickness $s_8 \approx 0.27$ mm), fibre orientation 0° / 90°

It is self-evident that the layer construction indicated provides only one example out of many conceivable layer constructions and can be modified in many ways within the scope of the invention.

Looking at the entire cross-section of the moulding tool shown in Figure 1 as a sandwich structure, layers 1 to 5 form the first sandwich cover layer. The 6th layer is the sandwich core and layers 7 and 8 form the second sandwich cover layer.

The woven-fabric-reinforced layers were impregnated with a cold-setting laminating resin which, following corresponding tempering, has thermal dimensional stability up to 140°C.

The mould cover layer of the layer thickness s_1 consists e.g. of a conventional mould cover layer resin with a thermal dimensional stability of 140°C. In comparison with the fibre-reinforced layers this layer is relatively thick. Due to the low rigidity compared with the layers of the carbon fibre woven fabric it influences the mechanical properties of the mould construction overall, but only slightly. The mould cover layer can be polished and its pore-free surface guarantees a high number of demouldings with low mould wear.

The glass fibre woven layer of the layer thicknesses s_2 and s_5 can be required for production reasons and is intended to ensure good adhesion between the mould cover layer s_1 and the layers of the carbon fibre woven fabric s_3 and s_4. These layers also have a low rigidity vis-à-vis the subsequent layers of the carbon fibre woven fabric and only slightly influence the mechanical properties of the mould construction overall.

The layers of the carbon fibre woven fabric s_3 and s_4 form both the electrical resistance heating layer and the substantial structural component of the first sandwich cover layer. Due to their high rigidity in comparison with the further layers they largely determine the mechanical properties and the thermal expansion of the first sandwich cover layer.

The glass fibre woven fabric layer s_5 can, like s_2, be required for production reasons and guarantees good adhesion between the layers of the carbon fibre woven fabric and the sandwich core s_6.

The layers of the carbon fibre woven fabric s_7 and s_8 form the second sandwich cover layer as a quasi-isotropic laminate construction.

As the thermal expansion of both sandwich cover layers is essentially determined by the carbon fibres, their thermal expansion and thus the possible heat distortion at different temperatures is very slight.

With the described construction of the moulding tool, the following considerations and properties essentially apply:

- An important component of the mould is a layer of carbon fibre woven fabrics in a plastic matrix, which assumes both the supporting function of the rear section of the mould and also serves directly as a heating layer in the form of electrical resistance heating through the supply of current to the carbon fibres. The carbon fibre woven fabric in the plastic matrix should so far as possible be constructed quasi-isotropically. The material costs for the moulding tool can be clearly reduced by integration of the mould heating and the supporting mould rear section. At the same time the amount of heat required for heating the mould is reduced. Moreover thermal stresses between different materials can thus be avoided.
- The carbon fibre woven fabric in the plastic matrix, which is as homogeneous as possible, forms an individual heating strand which is preferably connected in parallel in the longitudinal direction of the mould. Thus the heating element consists of a thin laminate layer. In the case of connection in the longitudinal direction of the mould the cross-section approximately corresponds to the product of the width “B” of the mould and thickness “s” of the carbon fibre woven fabric. In the present case the length “L” of the heating element corresponds approximately to the total length of the moulding tool.
- A resin-rich mould cover layer which guarantees a pore-free surface of the mould and good release action in component production will in general be required. This mould cover layer should, in so far as it is required, be as thin as possible and only slightly influence the mechanical and thermal properties of the layer of the carbon fibre woven fabric in the plastic matrix.
- The heated layer of the carbon fibre woven fabric in the plastic matrix, optionally in connection with the abovementioned mould cover layer, forms the actual mould surface, which is thin-walled overall and thus relatively flexible. For reinforcement

the moulding tool can be constructed in sandwich form. The core material of the reinforcing layer can be electrically insulating if a current flow to the second cover layer is to be prevented. Should the current flow to the second cover layer be desired, an electrically conductive core material of the reinforcing layer can also be used.

- The second mould cover layer preferably also consists of a quasi-isotropic carbon fibre woven fabric in a plastic matrix. Thus the thermal expansion of the moulding tool is essentially determined by two quasi-isotropic cover laminates. As these laminate constructions are known to exhibit only very slight thermal expansions in a wide temperature range, both thermal expansion and also heat distortion of the mould are very slight in the cover layers despite varying temperatures. If both cover layers exhibit only slight heat expansion, the bending deformation of the mould due to temperature influences remains very slight. Slight temperature-related bending deformations can in addition be reduced by increasing the core thickness without any substantial increase in the weight of the mould.
- Further layers can fitted intermediately at any position if e.g. electrical insulation of individual layers is desired or for processing reasons this seems expedient for sufficient adhesion of individual layers to each other. Care must be taken that additional layers are constructed in such a way that they do not, or only slightly, influence the mechanical properties and in particular the thermal expansion of the heating layer. In this case, in particular the use of aluminium honeycomb cores or carbon fibre honeycomb cores could be envisaged.

With respect to the design of the heating power of the moulding tool according to Figure 1 the following is significant:

The present heatable mould is, as an example, rectangular with a heated length L = 1,370 mm and a width of B = 557 mm. Only the layer s_3 was directly electrically contacted in the present case. For this, in each case 4 warp threads made of carbon fibres were crimped in a ferrule and soldered with an embedded earth strap. These warp threads run in the longitudinal direction of the mould and thus form a parallel circuit of the individual resistance threads. Weft threads of this woven fabric layer running crosswise thereto, also made of carbon fibres, are in principle not current-carrying in this arrangement, but can serve for potential equalization, e.g. should individual warp threads be damaged.

In the present case the following thus applies for the electrical resistance of the layer s_3:

$$R_3 = \frac{R_{spec,thread} \cdot L}{n}$$

Wherein:

R_3: electrical resistance of the 3rd layer

$R_{spec,\ thread}$: specific resistance of the individual warp thread

L: Length of the heating zone

n: Number of the warp threads connected in parallel

Tests have shown that further carbon fibre layers which are applied directly to the electrically contacted fibre layer have almost the same conductivity as the directly contacted layer. With fibres running diagonally, the correspondingly changed number of fibres per width as well as the resulting length are to be taken into consideration. In the present case the 4th layer, laid diagonally, has the same conductivity overall as the 3rd woven fabric layer.

Due to additional contact resistances a slightly higher value is measured on the mould than that resulting from the theoretical calculation. Here the measured resistance was approximately 12% above the previously calculated value.

Figure 2 shows the current, the heating power and the surface heating power of the mould, resulting in the case of predetermined heating voltage. As the ohmic resistance of the mould heating changes only slightly in the temperature range up to 100°C, the current increases linearly with the heating voltage, whereas the heating power increases with the square of the voltage.

It is moreover important here that the ohmic resistance is very low in the case of a corresponding construction with the result that even larger heated moulds can be heated with low voltage.

In various experimental set-ups it has been possible to show that the theoretically calculated ohmic resistance for different constructions of the heating layer agrees well with the measured values.

The temperature achieved in the case of corresponding mould heating at the mould surface, essentially depends on the following parameters:

- surface heating power in W/m^2
- ambient temperature
- heat flow in the mould
- media adjacent to the mould, which influence the transfer of heat to the environment.

It was clear that the achievable temperature is determined far less by the surface heating power than by the insulation.

For the operation of the moulding tool it has proved particularly advantageous if the moulding tool is thermally insulated.

With the simple hotplate described above, at room temperature (approximately 25°C) a surface temperature of 82°C should be achieved. Figure 3 shows the temperature curves for the hotplate with different insulations in the case of a surface heating power of 200 W/m^2. The temperature difference compared with the ambient temperature is shown.

Figure 3 clearly shows the influence of the insulation. Whilst a mere 12.9 K temperature increase was measured at the mould surface without insulation, with the same surface heating power a 33.6 K temperature increase was measured when a double fleece was applied. With an additional insulating board lying on the surface, the temperature increase with the same surface heating power amounted to 57.3 K.

This temperature increase is even more apparent if the mould is completely insulated. In a further test the heating power was halved to 100 W/m^2; the heated mould was insulated on the bottom and the top with a 40 mm thick insulating board. Temperatures 70 K above the ambient temperature were measured at the mould surface.

These measurements show that the heating power requirement can be significantly reduced by means of simple insulation. In all cases the heating rates were clearly above the required heating rates which in general should not exceed 10 K / hour in the case of components made of fibre-reinforced epoxy resins.

These studies show that special attention should be paid to the insulation. In particular it seems to be possible, in the case of predetermined heating power, to be able to influence the temperature curve in a targeted manner, optionally also partially, by adding or omitting insulating material. This should be useful e.g. in the case of complicated mould geometries, for which constant surface heating over the entire mould geometry may only be carried out with difficulty.

With respect to the possible uses of the moulding tool according to the invention, the following can be stated:

The possible uses of the heatable plastic moulds described above preferably lie in fields in which large-scale shell components with simple geometry are produced in smaller to medium quantities and are to be heated in the mould during or after moulding. In this case, moulds with the fibre-plastic systems studied to date can guarantee temperatures up to approximately 100°C. At the same time the temperature resistance is limited by the synthetic resin systems used. With further temperature-resistant resin systems thermal dimensional stabilities up to clearly above 200°C are possible, without the need for significant process changes during the production of the moulds. With ceramic matrix materials, however, moulds with substantially higher thermal dimensional stability could optionally also be constructed and heated in a similar manner.

Potential components that could be produced in corresponding moulds clearly more economically than hitherto are in particular large-scale fibre-composite components such as wing, fuselage or tail components in aircraft construction, panels for various transport systems or medical engineering, boat hulls or wind turbine blades. However, plastic components without fibre reinforcement can in principle also be produced in corresponding heatable plastic moulds.

Thus large deep-drawing moulds, such as e.g. rotational sintering moulds, could also be constructed as described.

P A T E N T K R A V

1. Formværktøj til den grunddannende eller omdannende formgivning af byggeelementer af termisk influerbare materialer, fortrinsvis af plast og især af fiberkompositmaterialer, hvor formværktøjet omfatter en fiberkompositstruktur og et elektrisk modstandsvarmelegeme, hvor der i fiberkompositstrukturen af formværktøjet nær den formgivende overflade af formværktøjet er indlejret kulfibre eller kulstoffilamenter i en plastmatrix, hvor kulfibrene eller kulfilamenterne i plastmatricen nær den formgivende overflade i det væsentlige bestemmer de mekaniske egenskaber, navnlig styrken, stivheden og/eller varmeudvidelsen, af formværktøjet

k e n d e t e g n e t ved, at

det elektriske modstandsvarmelegeme er forbundet således, at i det mindste enkelte dele af det elektriske modstandsvarmelegeme tilsammen danner en elektrisk parallelforbindelse, hvor indretningen, der udgør det elektriske modstandsvarmelegeme, er udformet i form af biaksiale eller multiaksiale væv eller ikke-vævede materialer af kulfibre eller kulfilamenter, og indretningen, der udgør det elektriske modstandsvarmelegeme, er udformet af kulfibre eller kulfilamenter delvis eller helt som enheder i form af ikke-vævede materialer, væv, hvor enhederne ved enderne af fibrene eller enhederne er elektrisk kontakteret og koblet med hinanden som en parallelforbindelse.

2. Formværktøj ifølge krav 1, k e n d e t e g n e t ved, at kulfibrene eller kulfilamenterne i plastmatricen er indlejret direkte tilstødende den mod byggeelementsiden vendende overflade af formværktøjet.

3. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at indretningen, der udgør det elektriske modstandsvarmelegeme, er udformet kvasiisotropt af kulfibre eller kulfilamenter eller deraf dannede enheder.

4. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at elektrisk ikke-ledende områder er udformet mellem de enkelte enheder af indretningen, som udgør det elektriske modstandsvarmelegeme, af kulfibre eller kulfilamenter.

5. Formværktøj ifølge krav 4, k e n d e t e g n e t ved, at de elektrisk ikke-ledende områder er indsat i et plan eller anbragt vinkelret mellem overhinanden liggende planer.

6. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at indretningen, der udgør det elektriske modstandsvarmelegeme, af kulfibre eller kulfilamenter eller deraf dannede enheder i plastmatricen i det væsentlige bestemmer de mekaniske egenskaber og varmeudvidelsen af hele fiberkompositstrukturen.

7. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at indretningen, der udgør det elektriske modstandsvarmelegeme, af kulfibre eller kulfilamenter eller deraf dannede enheder i plastmatricen danner den afgivne varmeeffekt direkte på overfladen af byggeelementet, som skal formes.

8. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at den overflade af formværktøjet, der vender mod byggeelementet, er dannet ved hjælp af et

formdæklag, som dækker det lag, der indeholder det elektriske modstandsvarmelegeme, på den modbyggeelementvendende side med et fortrinsvis tyndt lag.

9. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at et fortrinsvis elektrisk isolerende afstivende lag er påført på den side, der vender mod byggeelementet, af det lag, som har det elektriske modstandsvarmelegeme.

10. Formværktøj ifølge krav 9, k e n d e t e g n e t ved, at det afstivende lag omfatter en opbygning i form af et stabilt letvægtslag eller en sandwichopbygning.

11. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at der er anbragt yderligere fortrinsvis et elektrisk isolerende mellemlag mellem fiberkompositlaget der indeholder det elektriske modstandsvarmelegeme, formdæklaget og/eller det afstivende lag.

12. Formværktøj ifølge krav 11, k e n d e t e g n e t ved, at som yderligere mellemlag er der anbragt et lag af et fortrinsvis tyndt glasfibervæv i fiberkompositstrukturen.

13. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at et lag med kulfibre, som er indlejret i en plastmatrix, kan være tilvejebragt som det yderligere formdæklag, anbragt på den side af det afstivende lag, der vender væk fra byggeelementet.

14. Formværktøj ifølge krav 13, k e n d e t e g n e t ved, at kulfibrene af formdæklaget, der vender væk fra byggeelementet, er elektrisk isoleret mod kulfibrene i fiberkompositlaget, som vender mod byggeelementet, og som indeholder det elektriske modstandsvarmelegeme.

15. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at orienteringen af kulfibrene eller kulfilamenterne eller enhederne af kulfibre eller kulfilamenter er forskudte/eller fordrejede i forhold til andre kulfibre eller kulfilamenter eller enheder af samme fiberkompositlag.

16. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at de elektriske varmelegemer er segmenterede i strømmens strømningsretning og de enkelte segmenter kan slås helt eller delvist bro over ved hjælp af yderligere elektroniske byggeelementer, for at påvirke strømmens strømning og varmeeffekten i det tilsvarende segment.

17. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at de elektriske varmelegemer er segmenterede i strømmens strømningsretning og de enkelte segmenter af et varmelegeme danner en serieforbindelse.

18. Formværktøj ifølge krav 17, k e n d e t e g n e t ved, at de segmenterede elektriske varmelegemer kan betjenes samlet gennem serieforbindelsen med lav spænding selv ved store dimensioner af formværktøjet.

19. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at enkelte stromførende og overhinanden liggende lag af det elektriske varmelegeme er

isoleret i forhold til hinanden i tykkelsesretningen ved hjælp af tynde isolerende lag på en sådan måde, at en individuel segmentinddeling kan opnås ved stabling af tyndlagede varmelegemer med en flerlagteknik.

20. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at ved hjælp af yderligere tynde og lokalt begrænsede indsatte elektriske varmelegemer, kan strømmens strømning i formværktøjet ændres lokalt på en sådan måde, at en delvis ændring i fladevarmeeffekten inden i fladen af formværktøjet er mulig.

21. Formværktøj ifølge et af de foregående krav, k e n d e t e g n e t ved, at formen er gennemskåret af kanaler, igennem hvilke køleluft eller gasformige eller flydende kølemedier ledes.

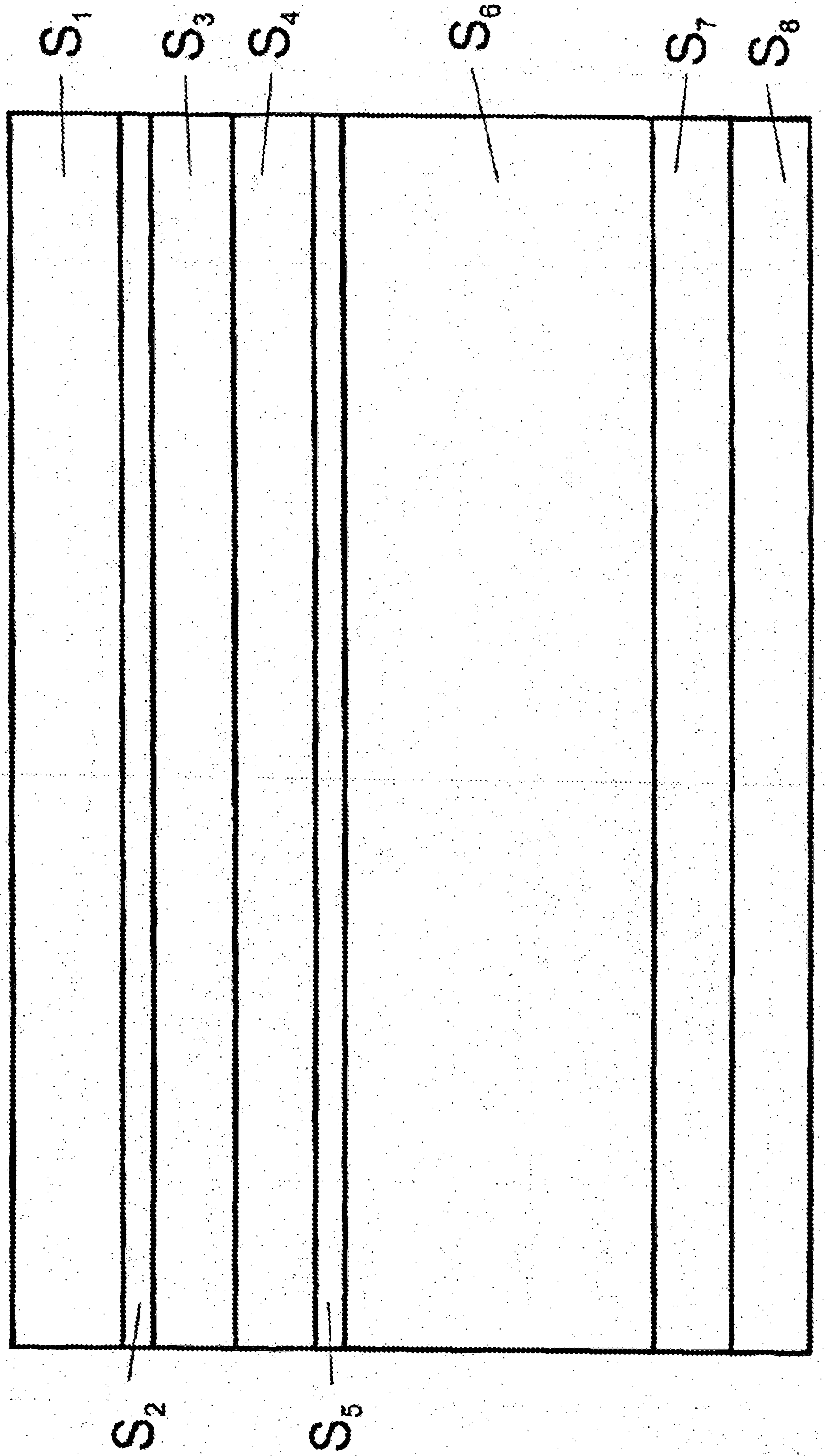

Fig. 1

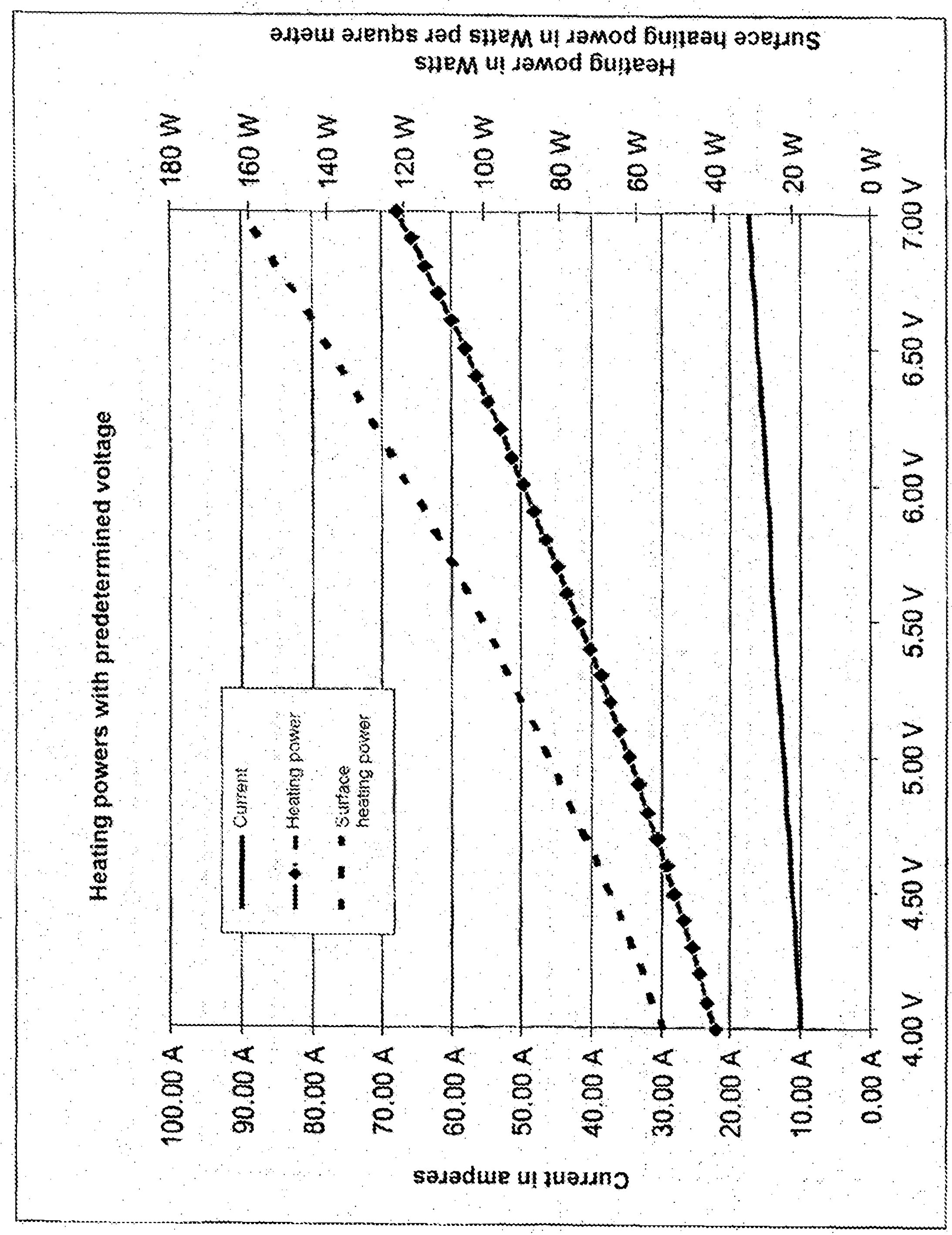
Heating powers with predetermined voltage
Current
Heating power
Surface heating power
Current in amperes
100.00 A
90.00 A
80.00 A
70.00 A
60.00 A
50.00 A
40.00 A
30.00 A
20.00 A
10.00 A
0.00 A
4.00 V
4.50 V
5.00 V
5.50 V
6.00 V
6.50 V
7.00 V
180 W
160 W
140 W
120 W
100 W
80 W
60 W
40 W
20 W
0 W
Heating power in Watts
Surface heating power in Watts per square metre

Fig. 2

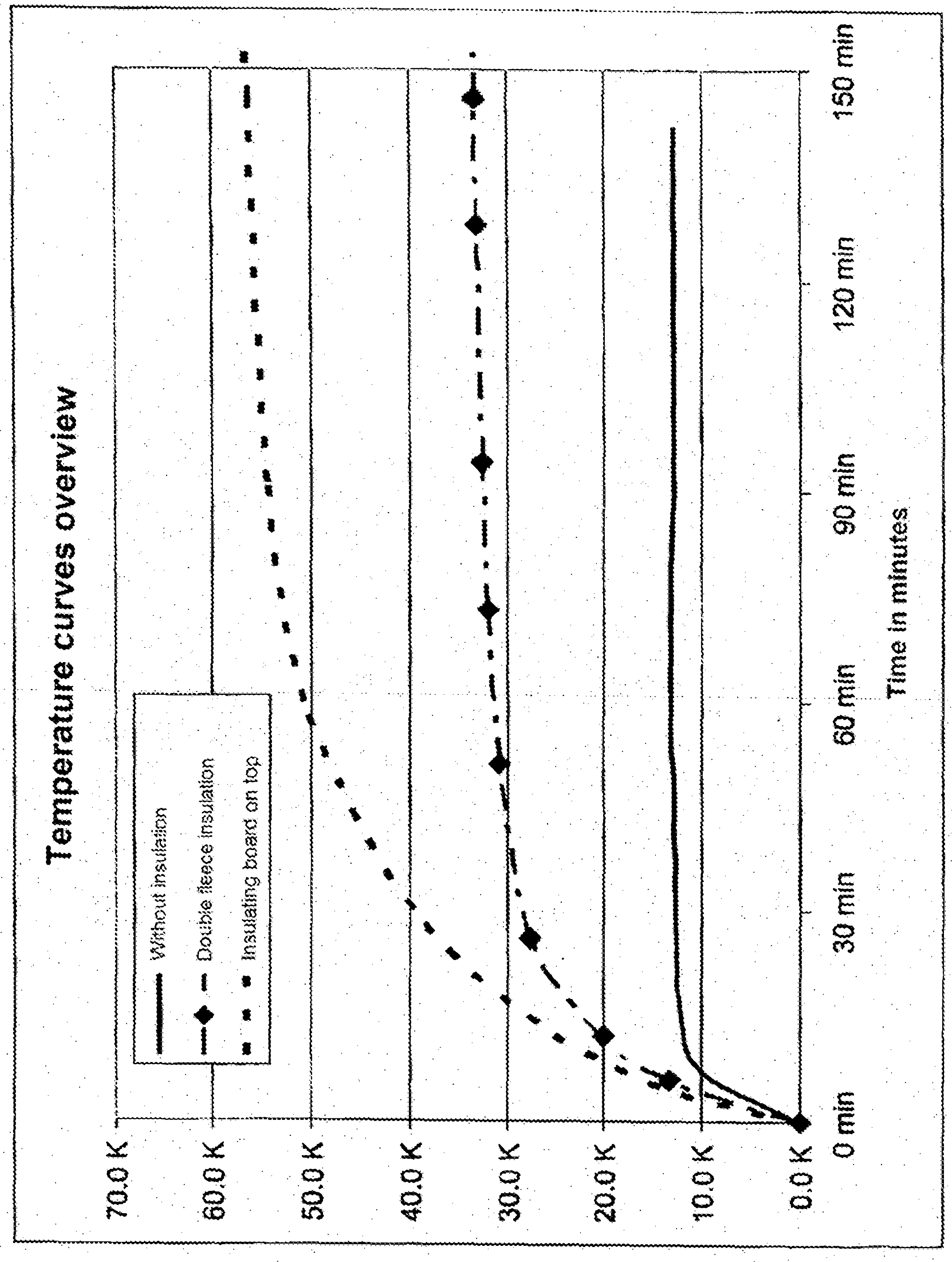
Temperature curves overview
Without insulation
Double fleece insulation
Insulating board on top
70.0 K
60.0 K
50.0 K
40.0 K
30.0 K
20.0 K
10.0 K
0.0 K
0 min
30 min
60 min
90 min
120 min
150 min
Time in minutes

Fig. 3