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## (54) NEAR SOLIDUS FORGING

(57) A method for hot-shaping a metal part, the method comprises heating the metal part to an intermediate temperature between the metal part hot forging temperature and above the beginning of the melting of said metal part or above the solidus temperature of said metal part, performing forging of said metal part and cooling said metal part, wherein the forging is performed with temperatures between 0.85-0.9 times a solidus temperature, Ts, of the metal part and a 5% of liquid fraction of the metal part when the metal part comprises globular microstructures or between 0.85-0.9 times the Ts of the metal part and a 20% of liquid fraction of the metal part when the metal part comprises non-globular microstructures and wherein the forging is performed in a closed die tooling.

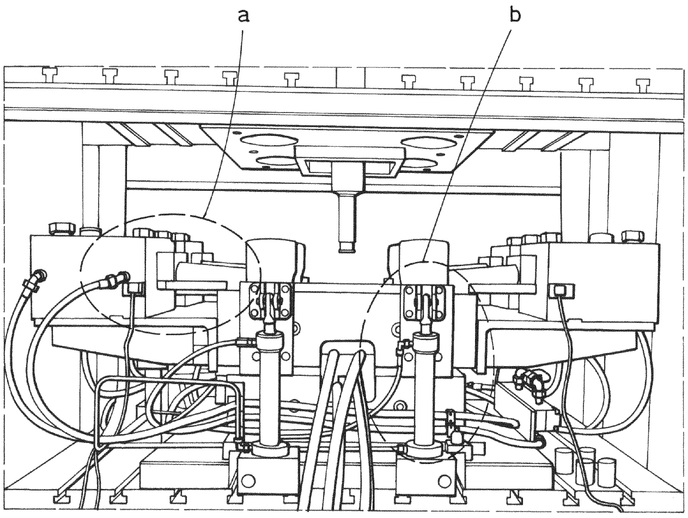



FIG.3

EP 3 804 878 A1

## Description

### Object of the invention

**[0001]** The present invention refers to a method for hot-shaping metal parts.

**[0002]** Particularly, the object of the present invention is to provide a method for hot-shaping metal parts to manufacture components with the same characteristics as the forged components, while allowing the manufacture of more complex geometries due to a fluidity of the material close to the fluidity in a semi-solid state.

### Background of the invention

**[0003]** The most simplistic definition of conventional forging is to cause a large plastic deformation in a massive material to achieve the objective geometry. In any case, and always respecting this premise of deforming a massive material, there are three main variants: cold forging, warm forging and hot forging. The selection of each one will depend on the geometry of the manufacturer, the characteristics of the component and the alloy to be used.

**[0004]** Cold forging is defined as the deformation of a massive material to achieve the objective geometry at room temperature. In this process, usually, quite symmetrical geometries and ductile materials are used, which often have a great plastic deformation. That is why the geometries that can be manufactured by this method are round (or almost round) and the chosen materials (usually steels and/or aluminum) are those that have a low strain hardening. The biggest advantage of this process lies, apart of those that are general to the forging process as an improvement in mechanical properties, in which large cadences are achieved (as the material does not have to be heated) and excellent dimensional tolerances and surface finishes.

**[0005]** In the case of warm forging, this consists, in the same way as in the previous case, in the deformation of a massive material, but this time at temperatures that do not exceed the recrystallization temperature of the chosen material (around 800°C for most steels). In a generic way, the process window of this type of forging can be classified at temperatures between 30% and 60% of the solidus temperature (Ts) of the material to be deformed (the Ts is the temperature at which the material begins to generate the first liquid fractions). The main rationale for heating the material at these temperatures is to continue maintaining acceptable dimensional tolerances (to minimize machining on many occasions) but with materials that are impossible to deform at room temperature. In this sense, when heating the material at these temperatures, the plastic deformation occurs with greater ease, being able to achieve slightly more complex geometries and requiring less effort to deform the material.

**[0006]** Finally, the hot forging performs the deformation of the massive material at temperatures greater than the recrystallization temperature of the material. In this sense, the maximum temperatures at which this process can be carried out are defined by the knowledge obtained with the "trial and error" method during the large number of years that this type of forging has been used. Therefore, and in a generic way, the process window for hot forging can be classified for temperatures between 60% and 85-90% of Ts. Above these temperatures, the material begins to show different problems, such as the so-called "overheating" and "burning", which could damage the mechanical properties of the component. The greatest advantage of hot forging compared to the previous two processes is the greater deformability of the material at high temperature, making it possible to obtain complex and slightly symmetrical geometries. In contrast, the ability to ensure good dimensional tolerances and surface finish is lost.

**[0007]** The manufacturing process known as Semi-Solid Metal Forming (SSM) comes from the discovery of thixotropic behavior in semi-solid metals. In some tests it was observed, accidentally, how the material reduced its viscosity under the influence of shear stresses and how, by letting the material rest for a long time, it recovered its initial state. This is due to the phenomenon of agglomeration/deagglomeration of the particles of the material that, under shear stresses, is co-inverted into a suspension of solid particles in a liquid matrix (deagglomeration). If this effort is no longer applied, the particles come together again generating new bonds between them (agglomeration). This phenomenon, therefore, implies that the material in semi-solid state can behave like a liquid if shear stresses are applied (it flows similarly to the liquid), but with solid particles already present that act as nuclei, improving the mechanical properties of the component.

**[0008]** For these previous conditions to occur, the material must consist of a globular microstructure, since, if the material is dendritic, the thixotropic properties cannot be obtained. In addition, for the material to flow as if it were liquid, the solid fraction must be up to 40%, although depending on the material this may be, exceptionally, somewhat larger. From this percentage, it would be possible to perform semi-solid shaping at high solid fractions. In general, the range of work for the high solid fraction regime is that between 60% and 90% of solid volume in the material since, below 60% the material is not able to maintain its own weight without deforming, and above 90% the material theoretically stops behaving as semi-solid to start behaving more like a solid.

**[0009]** In any case, as previously mentioned, in order to obtain the advantages of SSM forming, the material must consist of globular or semi-globular particles at the forming temperature. For this, the starting material has to be treated so that at the working temperatures said material comprises the required microstructure. That is why the SSM forming is divided into two routes called "rheo" and "thixo" processes.

**[0010]** The "rheo" processes are those in which the material melts completely and, during the solidification process up to the volume of solid required, the material is treated by different methods to obtain the required microstructure. In the case of "thixo" processes, the material is previously prepared so that, when reheating it to the desired temperature, it consists of the required microstructure. Figure 1 shows the differences between both processes graphically.

**[0011]** Once it has been decided which of the two methods of material preparation will be used, it only remains to define the type of process that will be used to manufacture the components. Figure 2 shows schematically different options for performing both "rheo" processes and "thixo" processes.

**[0012]** Hence a forging process that ensures good dimensional tolerances and surface finish achieving more complex geometries than in conventional forging is desired.

## Description of the invention

**[0013]** In the world of forging, and more specifically in that of hot forging, the upper limit of temperatures to be used is marked by the phenomena of "overheating" and "burning". In a generic and conventional way, and as it has been mentioned previously, hot processes are limited to temperatures between 0.6*Ts and 0.85-0.9*Ts.

**[0014]** Hence, when the condition of 0.85-0.9*Ts is exceeded, the material tends to overheat. This phenomenon can be defined as the excessive growth of the grains and embrittlement of the grain boundaries that, in the end, worsen the mechanical properties of the final component. There are some cases in which this situation can be reversed by heat treatment, however; this is not always possible and, therefore, these conditions are avoided.

**[0015]** Hence, at a temperature closer to Ts, the material tends to burn. The definition of this phenomenon is the fusion and/or oxidation of certain minor alloying elements that are generally found at the boundaries of the grain, thus generating defects related to the appearance of liquid such as pores or cracks. This phenomenon is impossible to recover and, therefore, the material in this state, as well as the components manufactured under these conditions, must be rejected.

**[0016]** Regarding the semi-solid forming at high solid fractions, the working temperature window for this process was defined generically for solid volumes between 60% and 90% measured by the DSC (Differential Scanning Calorimetry) technique. The lower limit of temperatures used for this process (90% of solid fraction) was defined as a limit since, as previously mentioned, the material stopped behaving as semi-solid to start behaving like a solid.

**[0017]** Therefore, there is a gap in terms of manufacturing between temperatures 0.85-0.9 * Ts and the 5% of liquid fraction (or even higher if the microstructure is not globular to allow thixotropic behavior). This window is usually between 200-150 °C in the case of steels in which hot forging is avoided to ensure integrity of the components. In the same way, the semi-solid forming does not even consider this window because it is assumed that the material loses the deformability properties of the semi-solid forming. Hence, it is precisely in this working window, i.e. having a lower limit of 0.85-0.9 * Ts and an upper limit of 5% of liquid fraction (wherein the upper limit may be even higher (~20%) if the material does not allow thixotropic behavior) in which the forging process according to the present invention which has been defined as Near Solidus Forging (NSF) process is established. The proposed forging process solves the problems encountered by both conventional and semi-solid forging as follows:

**[0018]** Overheating: The proposed forging process, when performed in a single step and at higher temperatures, implies a greater degree of deformation and a greater freedom to propagate and accumulate dislocations which, in the end, implies a greater possibility of generating different types of recrystallization. In this way, neither the growth of the grains nor the embrittlement of the grain boundaries presents an inconvenient since, during the process, the microstructure recrystallizes generating a new microstructural state.

**[0019]** Burning: The fusion of certain alloying elements during the process that tend to generate porosity or cracking is not a problem for the proposed forging process according to the present invention. Being a closed volume process (closed die forging), both pores and cracks tend to close due to the high temperatures and pressures generated during the process.

**[0020]** The semi-solid non-behavior: Although the material, a priori, does not show the deformability of the semi-solid material, the material is still in a state of great softening. This means that, despite not reaching such low stresses as in semi-solid forming, the material tends to flow in a similar manner.

**[0021]** In conclusion, what the NSF process allows is to manufacture components with the same characteristics as the forged components, while allowing the manufacture of more complex geometries due to a fluidity of the material close to the fluidity in a semi-solid state.

**[0022]** Hence, the NSF process achieves the following benefits:

The NSF process is a manufacturing process "near-net-shape", which means savings in the starting material (savings of around 20-25% have been recorded, but it depends on the geometry to be manufactured). The NSF process uses presses of lower tonnage than in conventional forging. The NSF process requires fewer forming stages than in conventional forging. Furthermore, a NSF manufactured component has the same properties as a forged one, and the process would be able to fill more complex geometries than in conventional forging.

**[0023]** In order to achieve the NSF process:

The material must be within the working window (0.85-9 * Ts and 5% liquid fraction or even greater if the material does not behave thixotropically). At these temperatures, material achieves a state of great fluidity (similar to semi-solid) that allows filling complex geometries, but without generating excessive liquid that could damage the mechanical properties; and

**[0024]** the tooling must be of closed volume. The microstructural state of the material can be affected at working temperatures due to excessive grain growth or generation of reduced amounts of liquid. So that these phenomena do not damage the final properties, both the degree of deformation that is generated at closed volume and the pressure exerted on the material in the final stages of filling the cavity are controlled so sound components are obtained.

**[0025]** Additionally, for an even better operation of the NSF process it may be convenient to fulfill the following premises:

Installation of a copper ring in the punch. The function of the copper ring avoids leaks of the material by the remaining space between the punch and the stamp. The copper ring, upon contact with the hot material, expands by covering any channel through which the material could be filtered. In this way, it would ensure a longer life of the punch and a lower need for starting material; and

**[0026]** Installation of lateral slides. Although this process can be carried out in a simple way with two stamps, various lateral slides can be added to the tooling to use a larger number of stamps and, thus, be able to manufacture geometries of greater geometric complexity.

**Brief description of the drawings**

**[0027]** For a better understanding the above explanation and for the sole purpose of providing an example, some non-limiting drawings are included that schematically depict a practical embodiment.

Figure 1 shows the differences between "rheo" and "thixo" processes.

Figure 2 shows different options for performing both "rheo" processes and "thixo" processes.

Figure 3 shows a preferred example of a tooling for the NSF process.

**Description of a preferred embodiment**

**[0028]** The proposed NSF process uses the following facilities and equipment to perform:

Heating equipment: The heating equipment can be both induction and resistance. The selection of the heating equipment may depend on the cycle time for the manufacture of the selected geometry since the inductors are able to heat the billets faster and vice versa. The equipment can be multi-seasonal or continuous. That is, different unit heating stations, or continuous equipment for series heating of the billets.

**[0029]** Press: The most important feature of the press is the capability to perform position control. In this way, the most suitable presses would be mechanics, servo-mechanics or hydraulics. Depending on the geometry to be manufactured, it may be more interesting to use a press with higher movement speed (mechanical or servo-mechanical press) or with the capability to perform the process at constant speed or force (hydraulic press). The use of hammer presses may be possible if a designed tool can ensure a "limit switch" that can control the final position of the NSF process.

**[0030]** Closed tooling: Closed tooling is essential for proper manufacturing using NSF. The tooling must consist of a minimum of 2 stamps with a system that ensures that they cannot be separated during the process. Additionally, for more complex geometries, a tool with more molds can be designed using lateral slides like aluminum injection. In any case, it must be ensured that all semi-molds continuously maintain the enclosure. In this case, the enclosure is secured by heavy-duty hydraulic cylinders (a) that block any separation of the mold as shown in figure 3 that shows a preferred example of a tooling for the NSF process. For the opening and closing movements of the molds, several hydraulic cylinders (b) with flow dividers are used to ensure a constant and controlled movement.

**[0031]** Punch: The punch is the element that accesses the closed tool to deform the material and distribute it through the cavity. The closed tool may comprise at least an upper mold and a lower mold (more if lateral slides are used). This element is cylindrical and must be machined under a specific geometry (defined according to its diameter) for the insertion of a copper ring. The copper ring is designed to be in constant contact with the upper die at the end of the forming stage, avoiding any material infiltration.

**[0032]** Tempering machine: The molds are preheated at a temperature between 270°C and 300°C to reduce the initial thermal shock between the hot billet and the mold, and to act as a refrigerator in the mass production of components. To do this, an oil temper unit as tempering machine may be used which, by means of the flow of the tempered oil, the molds are heated.

**[0033]** The NSF process consists of different stages during the process segmented as follows:

- Initial preparations: Before starting the manufacturing of components, the molds may be preheated by means of the tempering machine at a temperature between 270 °C and 300 °C by mechanized cooling channels. Furthermore, a selected lubricant can be applied on the mold footprint. Then, the closing and locking of the tooling can be performed.
- Material heating: The billets can be heated by induction or resistance furnace. If it is a multi-stationary equipment, the same heating cycle should be defined for each station depending on the cadence of the cell. If it is a continuous heating, the heating cycle must be designed in order to be able to provide a billet already heated depending on the production

speed. The ideal temperatures for the billets will depend on each material and geometry, but in their totality, they fall within the window of 0.85-0.9 * Ts and 5% of liquid fraction (this last value may be greater, up to 20%, if the material does not consist of globular particles in a liquid matrix that allows thixotropic behavior).

- Transfer of the billet: Once the billet has been heated at its optimum temperature, it must be transferred from the heating equipment to the tooling. This process can be done by an operator or a robotic arm to reduce the transfer time and, thus, reduce the heat loss that could be generated. The billet can be introduced through an upper cavity of the tooling which is the hole through which the punch enters.
- Deformation of the billet: Once the billet is inside the tooling, the press begins its deformation cycle (which will depend on the chosen press) by moving the punch (anchored in the upper table of the press) to the lower position, which is defined by the position control that has been stipulated depending on the geometry of the stamps. Once the punch has reached the lowest point of its movement, it returns to the initial position, ending the deformation stage. If required, the punch can be held at the lower point for several seconds by applying some pressure to avoid cracking or the closing of material pores.
- Expulsion of the component: Once the deformation is finished, the tooling is unlocked and opened, in this case, by means of the hydraulic cylinders. Once opened, the press pad ejects the component to be removed manually or by a robot or actuator. The stamp of the impurities that may have remained of this cycle is cleaned and the cycle would be repeated from the beginning.

**[0034]** Even though reference has been made to a specific embodiment of the invention, it is obvious for a person skilled in the art that forging processes described herein are susceptible to numerous variations and modifications, and that all the details mentioned can be substituted for other technically equivalent ones without departing from the scope of protection defined by the attached claims.

## Claims

**1.** A method for hot-shaping a metal part, the method comprises:

- heating the metal part to an intermediate temperature between the metal part hot forging temperature and above the beginning of the melting of said metal part or above the solidus temperature of said metal part;
- performing forging of said metal part; and
- cooling said metal part,

wherein the forging is performed with temperatures:

between 0.85-0.9 times a solidus temperature, Ts, of the metal part and a 5% of liquid fraction of the metal part when the metal part comprises globular microstructures; or
between 0.85-0.9 times the Ts of the metal part and a 20% of liquid fraction of the metal part when the metal part comprises non-globular microstructures, and
wherein the forging is performed in a closed die tooling.

**2.** The method according to claim 1, wherein the forging is performed using a copper ring installed in a punch.

**3.** The method according to claims 1 or 2, wherein the forging is performed with more than two closed dies comprising different lateral slides.

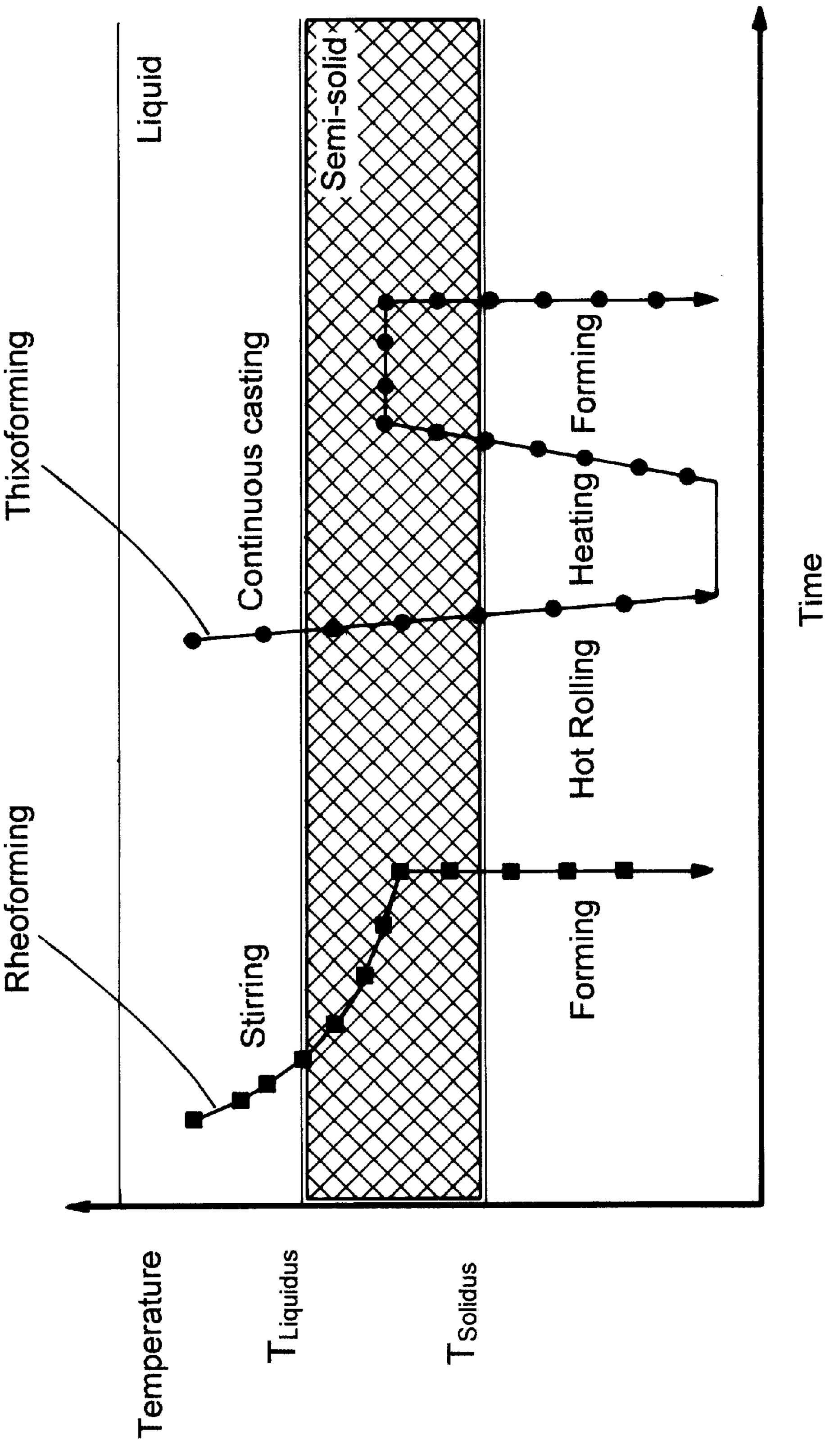
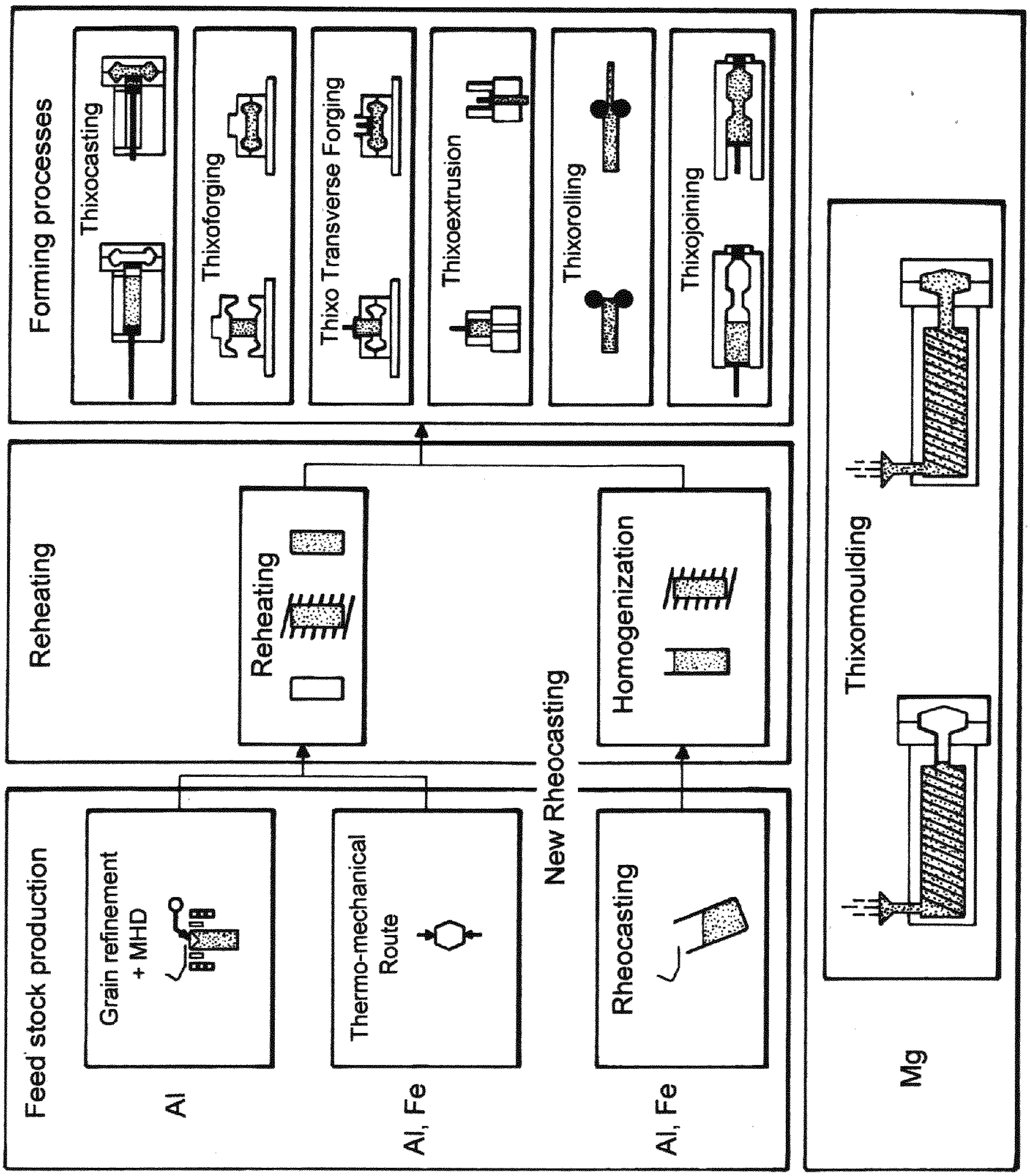

Liquid
Semi-solid
Thixoforming
Continuous casting
Heating
Forming
Hot Rolling
Rheoforming
Stirring
Forming
Time
Temperature
$T_{Liquidus}$
$T_{Solidus}$

FIG.1

FIG. 2


Feed stock production
Al
Grain refinement
+ MHD
Al, Fe
Thermo-mechanical
Route
New Rheocasting
Al, Fe
Rheocasting
Reheating
Reheating
Homogenization
Forming processes
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Thixoforging
Thixo Transverse Forging
Thixoextrusion
Thixorolling
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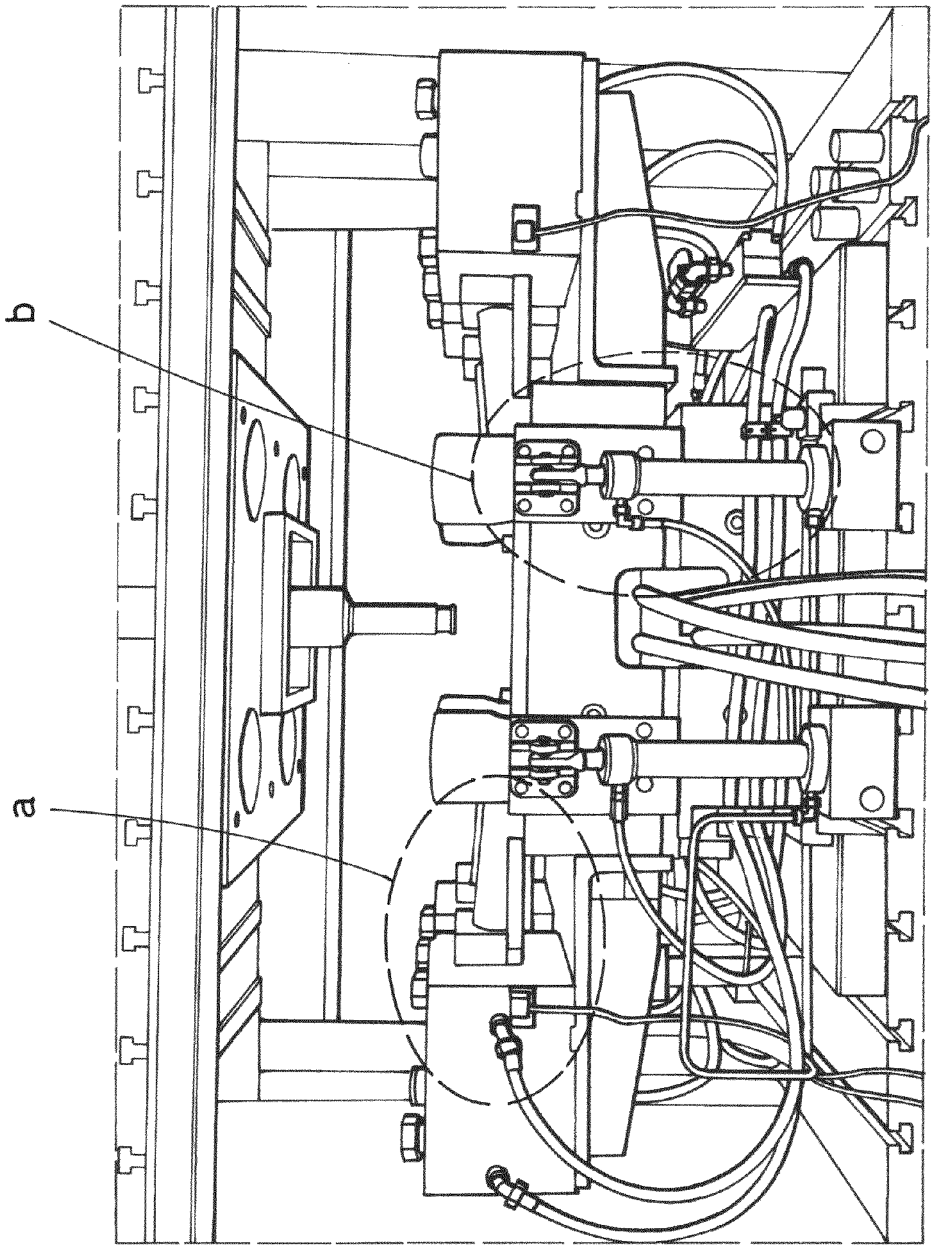


FIG.3

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# EUROPEAN SEARCH REPORT

Application Number
EP 19 38 2893

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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
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The present search report has been drawn up for all claims

1

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 8 April 2020 | Charvet, Pierre |

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