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(54) **METHOD OF FABRICATING INCONEL 718 TYPE NICKEL SUPERALLOYS**

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(57) **ABSTRACT**

A method of fabricating Inconel 718 type nickel superalloys. A last forging operation to which the nickel superalloy is subjected is such: that it takes place at a temperature lower than the δ-solvus temperature; that at all points of the nickel superalloy the local deformation ratio is not less than a minimum value; and that the nickel superalloy is not subjected to any heat treatment at a temperature higher than a threshold temperature equal to 750° C. after a quenching.

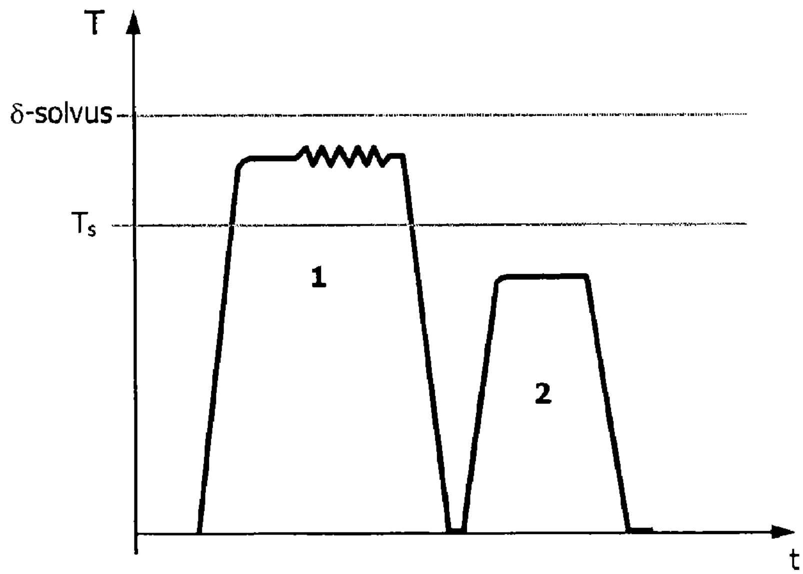

FIG.1

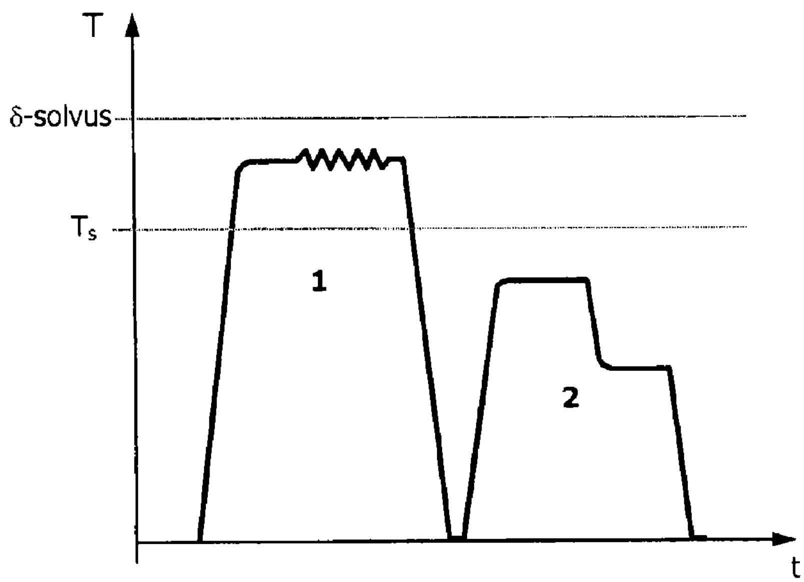

FIG.2

METHOD OF FABRICATING INCONEL 718 TYPE NICKEL SUPERALLOYS

[0001] The present invention relates to a method of fabricating Inconel 718 type nickel superalloys.

[0002] The Inconel 718 nickel-based superalloy (NC19FeNb) is in widespread use for fabricating parts in high-technology applications, in particular in aviation for rotary parts of turbine engines, casings, and rings. The mechanical characteristics that these parts present in use depend both on the intrinsic characteristics of the alloy (chemical composition) of the part, and also on the microstructure of the part, in particular on its grain size. In particular, grain size governs characteristics concerning low-cycle fatigue, traction strength, and creep. A microstructure in which the grains are fine (e.g. having grain size lying substantially in the range 5 micrometers (μm) to 20 μm) makes it possible to obtain better properties in terms of fatigue and traction strength, while also guaranteeing good creep behavior.

[0003] At present, this fine grain size is obtained by applying heat treatment and forging procedure plans to the part that serve to produce mechanisms for re-crystallizing the grains.

[0004] Nevertheless, with present procedure plans, zones of coarse grains are frequently observed on nickel superalloy parts, i.e. zones having grains of a size that is considerably greater than the size of fine grains. Such zones are undesirable since they give rise to a reduction in the mechanical properties of such parts.

[0005] These coarse-grained zones appear even when the procedure plans comprise forging operations below the δ-solvus temperature (the temperature at which delta precipitates go back into solution), even though such operations have the reputation of having no effect on the final microstructure of the alloy, since theoretically they are assumed to guarantee that there will be no grain growth.

[0006] The invention seeks to propose a fabrication method that makes it possible to limit the appearance of coarse grains during fabrication of the part.

[0007] This object is achieved by the fact that the last stage of forging to which said nickel superalloy is subjected is such: that it takes place at a temperature T lower than the δ-solvus temperature; that at all points M in the nickel superalloy the local deformation ratio D is not less than a minimum value D_m, where the local deformation ratio D is defined as

$$D = \mathrm{Ln}\left(\frac{\delta_i}{\delta_f}\right)$$

where δ_i is the initial distance between the point M and a point M' neighboring the point M, and δ_f is the distance between the points M and M' after forging; and that said nickel superalloy is not subjected to any heat treatment at a temperature higher than a threshold temperature T_S equal to 750° C. after said quenching.

[0008] By means of these provisions, any coarse grains still present in the superalloy are transformed back into the fine grains, and new coarse grains do not form within the superalloy.

[0009] Advantageously the nickel superalloy is also subjected to tempering directly after the quenching following the last forging step.

[0010] Thus, the toughness properties of the superalloy are improved, while its other mechanical properties are not significantly diminished. The tempering operation takes place at a temperature that is low enough to avoid recreating coarse grains within the superalloy.

[0011] The invention can be better understood, and its advantages appear more clearly on reading the following detailed description of an implementation shown by way of non-limiting example. The description refers to the accompanying drawings, in which:

[0012] FIG. **1** is a diagram showing the fabrication method of the invention; and

[0013] FIG. **2** is a diagram showing an example of the fabrication method of the invention.

[0014] In the present invention, consideration is given to nickel superalloys of the Inconel 718 type.

[0015] In the method of the invention, the starting billet has already been subjected to thermomechanical treatments for the purpose of giving the billet a structure and a shape that comply with specifications.

[0016] On examining prior art nickel superalloys in which the microstructure presents coarse grains, the inventors have observed that those coarse grains are of two different kinds.

[0017] Thus, a distinction is made between firstly coarse equiaxed grains that result from static enlargement of fine grains, e.g. because the alloy is maintained at a temperature higher than the δ-solvus temperature. Such enlargement may be avoided by performing the forging operations of the alloy treatment procedure plan at temperatures lower than the δ-solvus temperature.

[0018] Unexpectedly, within the alloy, the inventors have also observed "exploded" or "burst" coarse grains with outlines that are very irregular. It is thought that these grains generally form at temperatures lower than the δ-solvus temperature, and that, when the deformation is performed at temperatures lower than the δ-solvus temperature (e.g. lower than 1000° C.) it is the energy stored as a result of the work hardening during the preceding forging operation, that gives rise to this bursting of the grains. This stored energy is then "released" in the form of early and uncontrolled migration of the grain boundaries, thereby generating these "burst" grains.

[0019] According to the invention, and as shown in FIG. **1**, it is ensured that in the forging procedure plan to which the superalloy is subjected, the last forging step (referenced **1** in FIG. **1**) takes place at a temperature T that is lower than the δ-solvus temperature, and also that at all points M of the nickel superalloy, the local deformation ratio D is not less than a minimum value D_m.

[0020] The local deformation ratio D characterizes the local deformation at a point M of a material. It is defined by the equation

$$D = \mathrm{Ln}\left(\frac{\delta_i}{\delta_f}\right)$$

where δ_i is the initial distance between the point M and a point M' neighboring the point M, and δ_f is the distance between the points M and M' after forging.

[0021] Performing this last forging step at a temperature T lower than the δ-solvus temperature makes it possible to avoid forming coarse equiaxed grains.

[0022] Furthermore, the condition that the local deformation ratio D is not less than a minimum value D_m in a region of the superalloy enables the "burst" grains to be re-crystallized as fine grains in this region. During the forging step, and depending on the final shape given to the part, certain regions of the part may be subjected to greater amounts of deformation than other regions. The fact that the above condition concerning the local deformation ratio D is valid at all points M in the superalloy makes it possible to ensure that the "burst" grains are re-crystallized as fine grains throughout the volume of the superalloy.

[0023] For example, the minimum value D_m may be equal to 0.7.

[0024] Alternatively, the minimum value D_m may be equal to 0.8 or 0.9.

[0025] After this forging, the superalloy is subjected to quenching from the forging temperature T to ambient temperature T_A.

[0026] Advantageously, quenching is performed at a rate of about 15 degrees Celsius per minute (° C./min), since tests performed by the inventors have shown that mechanical characteristics are best optimized when quenching at that rate. Quenching is preferably performed with water.

[0027] Furthermore, after this quenching following the final forging step, the superalloy is not subjected to any heat treatment at a temperature higher than a threshold temperature T_S equal to 750° C.

[0028] Heat treatment at a temperature higher than the threshold temperature T_S would be likely to give rise to "burst" grains within the superalloy.

[0029] In particular, the superalloy it is not subjected to solution annealing since that takes place at a temperature higher than the threshold temperature T_S.

[0030] In contrast, the superalloy may be subjected directly to tempering (step referenced **2** in FIG. **1**) after the quenching following the last forging.

[0031] For example, the superalloy may be heated to a temperature of 720° C. for 8 hours, and then cooled to a temperature of 620° C. for 8 hours, prior to being cooled down to ambient temperature. This situation is shown in FIG. **2**.

[0032] Prior to the last forging step of the invention, the superalloy may have been subjected to no other, to one other, or to several other forging steps, with each, several, one, or none of these steps taking place at a forging temperature higher than the δ-solvus temperature.

[0033] Advantageously, all of the forging steps preceding the last forging step are performed at temperatures lower than the δ-solvus temperature.

[0034] Digital simulations have been performed by the inventors and they show that at the end of the method of the invention, the size of the grains is indeed reduced.

[0035] For example, at the end of a method of the invention, the size of all of the grains of the superalloy may lie in the range 5 μm to 30 μm.

[0036] Advantageously, at the end of a method of the invention, the size of all of the grains of the superalloy may lie in the range 5 μm to 20 μm. This fine mean grain size gives rise to a superalloy having a fatigue lifetime and an elastic limit that are further improved.

1-6. (canceled)

7. A fabrication method of fabricating an Inconel 718 type nickel superalloy wherein a last forging operation to which the nickel superalloy is subjected is such:

that it takes place at a temperature lower than the δ-solvus temperature;

that at all points of the nickel superalloy the local deformation ratio is not less than a minimum value; and

the nickel superalloy is not subjected to any heat treatment at a temperature higher than a threshold temperature equal to 750° C. after a quenching.

8. A fabrication method according to claim **7**, wherein the minimum value of the local deformation ratio is equal to 0.7.

9. A fabrication method according to claim **7**, wherein the nickel superalloy is also subjected to tempering directly after the quenching following the forging operation.

10. A fabrication method according to claim **7**, wherein all of forging operations preceding the last forging operation are performed at temperatures lower than the δ-solvus temperature.

11. A fabrication method according to claim **7**, wherein at an end of the method, a size of all grains of the superalloy lies in a range of 5 μm to 30 μm.

12. A fabrication method according to claim **11**, wherein at the end of the method, the size of all the grains of the superalloy lies in a range of 5 μm to 20 μm.

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