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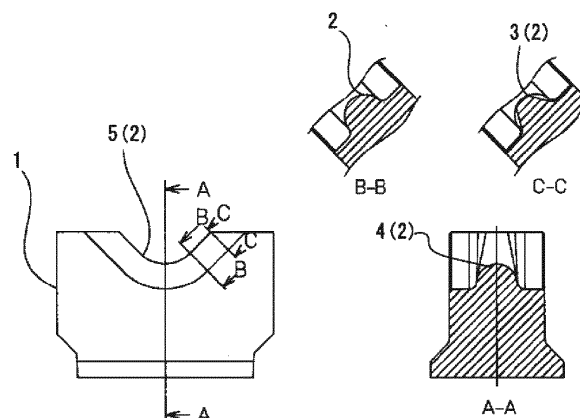
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(54) **HOT FORGING DIE AND HOT FORGING METHOD**

(57) Provided are a hot forging die and a hot forging method which enables to perform necking easily using a radial forging machine, even with difficult-to-work materials used for turbine blades. The hot forging die for hot-forging a rod-shaped forging material by radial forging includes a pair of halved pressing portions between which the forging material is interposed, each of the halved pressing portions having a convex portion having a substantially semicircular cross-section, the convex portion being continuous so as to surround the forging material, wherein each of the halved pressing portions includes a rough processing portion and a finishing portion having a convex portion having a larger curvature radius than the rough processing portion.



**FIG. 1**

**Description**

[PTL 1] JP-A-63-238942

[PTL 2] JP-A-60-250843

## Technical Field

**[0001]** The present invention relates to a hot forging die and a hot forging method.

## Background Art

**[0002]** For example, during the manufacturing of a turbine blade, a hot forging material having a round rod shape is stretched to a desired diameter, and a preform having a desired round rod shape in which the volume of a portion for forming a root portion or a wing portion of a turbine blade is secured is formed by closed die forging such that a turbine blade material having a near net shape is obtained. Regarding the shape of the preform, for example, Fig. 2 of JP-A-63-238942 (PTL 1) shows a preform having a shape in which a portion for forming a root portion is thick (the volume is high) and is gradually tapered toward a tip of a wing portion.

**[0003]** For example, a specific manufacturing method of the preform includes: radially forging a hot forging material having a round rod shape to obtain a long round bar material having a desired diameter; cutting the long round bar material in a predetermined dimension; and forging the cut round bar material into a desired preform shape using a separate open die forging machine.

**[0004]** During closed die forging of a turbine blade, a portion for forming a root portion or a wing portion, or a protrusion called a boss portion may be provided in a wing portion of the turbine blade. In this case, it is important to adjust the volume and the dimension of a preform for a turbine blade. In a case where the adjustment of the volume and the dimension is insufficient, a preform does not sufficiently fulfill in a die face during closed die forging. Therefore, there is a problem in that a part of a turbine blade material having a near net shape is deficient after closed die forging. In addition, a material of a turbine blade is an expensive alloy such as a Ni-based superalloy or a Ti alloy. Therefore, in a case where a problem, such as deficiency of a part of a turbine blade material having a near net shape after closed die forging, occurs, the damage is significant.

**[0005]** Therefore, it is preferable to provide a groove by processing called "necking" during the manufacturing of a preform such that the preform sufficiently fulfills in a die face during closed die forging. However, for example, as disclosed in JP-A-60-250843 (PTL 2), a processing groove may be sequentially formed by necking in a material having a round rod shape using a special jig in a press machine.

## Citation List

## Patent Literature

**[0006]**

## Summary of Invention

## Technical Problem

**[0007]** Regarding a shape of the jig disclosed in PTL 2 which is used for necking, a pressing portion of the jig is formed flat to have the same width. Therefore, the jig is not suitable for forming a desired groove in a difficult-to-work material. Further, a groove formed by necking has a small width and is vertically deep. In a case where a groove is formed in a direction perpendicular to a depth direction of a forging material, there is a problem in that an overlap defect occurs during hot forging in which the forging material is stretched to the length of a turbine blade.

**[0008]** An object of the present invention is to provide a hot forging die and a hot forging method, in which even a difficult-to-work material used for a turbine blade can be easily necked using a radial forging machine.

## Solution to Problem

**[0009]** The present invention has been made in consideration of the above-described circumstances.

**[0010]** That is, according to the present invention, there is provided a hot forging die for hot-forging a rod-shaped forging material by radial forging, the hot forging die including

a pair of halved pressing portions for interposing the forging material between the pair of the halved pressing portions,

in which each of the halved pressing portions being a convex portion having a substantially semicircular cross-section, the convex portion being continuous so as to surround the forging material, and

each of the halved pressing portions includes a rough processing portion and a finishing portion being a convex portion having a larger curvature radius than the rough processing portion.

**[0011]** In the hot forging die, it is preferable that each of the halved pressing portions includes a gradual change portion in which a curvature radius of the halved pressing portion gradually increases in a direction from the rough processing portion to the finishing portion.

**[0012]** In the hot forging die, it is more preferable that a curvature radius of the convex portion having a substantially semicircular shape in the finishing portion is larger than a curvature radius of a convex portion having a substantially semicircular shape in the rough processing portion by 10 mm or more.

**[0013]** In the hot forging die, each of the halved pressing portions has a pressing portion for necking.

**[0014]** In the hot forging die, a plurality of the pressing portions for necking are provided in a longitudinal direction of the forging material.

**[0015]** In addition, according to the present invention, there is provided a hot forging method for hot-forging a rod-shaped forging material by radial forging by using hot forging die comprising a pair of halved pressing portions for interposing the forging material between the pair of the halved pressing portions, each of the halved pressing portions being a convex portion having a substantially semicircular cross-section, the convex portion being continuous so as to surround the forging material, each of the halved pressing portions including a rough processing portion and a finishing portion being a convex portion having a larger curvature radius than the rough processing portion. The hot forging method includes:

a forging material heating step of heating the forging material to a hot forging temperature, and  
a hot forging step of necking the forging material by rotating the heated forging material and concurrently pressing the forging material with the hot forging die at the pair of the halved pressing portions facing each other.

**[0016]** In the hot forging method, it is preferable that the rod-shaped forging material is formed of a Ni-based heat-resistant superalloy or a Ti alloy.

**[0017]** The hot forging method according to the present invention is suitable for manufacturing a preform for a turbine blade.

#### Advantageous Effects of Invention

**[0018]** According to the present invention, even a difficult-to-work material used for a turbine blade can be easily necked using a radial forging machine.

#### Brief Description of Drawings

#### **[0019]**

Fig. 1 is a schematic diagram showing an example of a hot forging die according to the present invention.

Fig. 2 is a schematic diagram showing an example of the hot forging die according to the present invention.

Fig. 3 is a schematic diagram showing an example of a stretching portion.

Fig. 4 is a schematic diagram showing a radial forging machine.

Fig. 5 is a schematic diagram showing an example of a shape of a preform.

Fig. 6 is a schematic diagram showing an example of a portion that presses a forging material when the hot forging die according to the present invention is used for hot forging.

Fig. 7 is a schematic diagram showing an example of a portion that presses a forging material when the hot forging die according to the present invention is

used for hot forging.

Fig. 8 is a schematic diagram showing an example of a stretching portion.

#### 5 Description of Embodiments

**[0020]** In PTL 2, an object for necking is a small product called a connecting rod. On the other hand, the size of a turbine blade has increased recently, and a material thereof is a Ni-based heat-resistant superalloy or a Ti alloy which is known as a difficult-to-work material. In particular, some of the alloys have a small temperature range where hot forging is possible. Therefore, the temperature of a forging material which is formed of this alloy decreases during open die forging in which a jig for necking is used. Therefore, although dependent on the weight of a forging material, for example, a forging material for a 40 to 60-inch turbine blade is required to be reheated seven to ten times. As the size of a turbine blade increases, the number of times of reheating increases.

**[0021]** In order to solve the problem, it is extremely effective to use a radial forging machine for necking. However, in a radial forging machine, typically, a die called an anvil having a flat pressing portion is used. Therefore, a radial forging machine in which an anvil of the related art is used cannot be used for necking.

**[0022]** The present invention can solve this problem, and the greatest feature thereof is a novel shape which is applicable to formation of a preform for a large turbine blade using a radial forging machine. Hereinafter, a hot forging die used in the present invention will be described.

**[0023]** Fig. 1 shows a schematic side view showing a hot forging die 1 according to the present invention, a cross-sectional view (cross-sectional view A-A) showing a finishing portion of the hot forging die 1, a cross-sectional view (cross-sectional view C-C) showing a rough processing portion of the hot forging die 1, and a cross-sectional view (cross-sectional view B-B) showing a space between the finishing portion and the rough processing portion. In the present invention, a radial forging machine that presses a forging material in two directions opposite to each other is used. In Fig. 1, in a region from a position shown in the cross-sectional view C-C to a position shown in the cross-sectional view B-B, the curvature radius of each of the halved pressing portions shown in the cross-sectional views gradually increases. In a region from the position shown in the cross-sectional view B-B to a position (bottom) shown in the cross-sectional view A-A, the curvature radius is substantially the same. "The finishing portion" described in the present invention refers to a portion having the same curvature radius which includes the position (bottom) shown in the cross-sectional view A-A.

**[0024]** Two hot forging dies 1 shown in Fig. 1 are set as a pair. For example, as shown in Fig. 4, the two hot forging dies are facing each other such that a forging material 21 is interposed therebetween, and the pair of two hot forging dies 1 cooperate together for necking.

Specifically, the two hot forging dies 1 shown in Fig. 1 are set as a pair, and include halved pressing portions 2 between which the forging material (not shown in Fig. 1) is interposed. The forging material is interposed between the halved pressing portions and pressed. The forging material is held and intermittently rotated by a holding mechanism included in a radial forging machine.

**[0025]** As shown in the schematic side view of Fig. 1, each of the halved pressing portions 2 has a convex portion having a substantially semicircular cross-section which is continuous so as to surround the forging material. Since the pressing portions are halved, the forging material can be interposed between the pressing portions of the two hot forging dies that cooperate together. In addition, "the shape which is continuous so as to surround the forging material" refers to a shape in which the periphery of the forging material 21 is surrounded by the rough processing portions and the finishing portions as shown in Fig. 4. The halved pressing portion 2 is formed such that a concave is formed on a flat surface, and the pressing portion has an arc shape when seen from a side of the halved pressing portion 2 (in the schematic side view of Fig. 1). The halved pressing portion 2 includes a finishing portion 4 and rough processing portions 3. The finishing portion 4 is formed around the concave (arc-shaped) bottom, and the rough processing portions 3 are formed on each of both sides (both end sides of the concave (arc-shaped) portion) of the finishing portion. The distance between the rough processing portions increases in a direction from the bottom of the finishing portion 4 to the end portions of the opposite rough processing portions 3. When the two hot forging dies press the forging material, the forging material can be pressed in a continuous substantially semicircular convex shape. In a case where the forging material is hot-forged by the hot forging die 1 having the above-described shape, the convex rough processing portions formed in the hot forging die comes into contact with the forging material first such that a necessary groove can be sequentially formed by necking. Therefore, "the convex portion having a substantially semicircular cross-section" described in the present invention refers to a shape when seen from the direction of the respective cross-sectional views. That is, the cross-section refers to a cross-section when seen from a direction perpendicular to a longitudinal direction of the forging material.

**[0026]** In addition, each of the halved pressing portions 2 includes the rough processing portion 3 and the finishing portion 4 having a convex portion having a larger curvature radius than the rough processing portion. The reason for this is as follows. In the initial stage of forging, the contact area is reduced for effective necking such that a groove having a predetermined depth can be efficiently formed even in a difficult-to-work forging material when the forging of the forging material starts from the rough processing portions. Along with the progress of forging, the forging material is sequentially pressed toward the finishing portion such that the width of the

groove increases and a necking shape is adjusted. Even after hot forging by the finishing portion, the depth of the groove may not reach a necking depth. Therefore, even in the finishing portion, the contact area is reduced as much as possible by forming a pressing portion having a substantially semicircular cross-section. As a result, the necking shape can be efficiently adjusted.

**[0027]** That is, in the present invention, initially, the groove can be efficiently formed by the rough processing portion 3 having a small curvature radius. Next, the groove can be formed in a final shape by the finishing portion 4 having a larger curvature radius than that of the rough processing portion 3. Therefore, a gradual change portion can be formed, in which the curvature radius gradually increases from the substantially semicircular pressing portion formed in the rough processing portion 3 and in which the curvature radius in the convex finishing portion 4 is larger than that of the rough processing portion.

**[0028]** In the actual pressing portion, a substantially semicircular convex portion may be formed, for example, by build-up welding, and then the shape may be manually machined. Therefore, the formed convex portion does not necessarily have the same curvature radius. Therefore, "the substantially semicircular" described in the present invention only has to be a convex shape having a curvature which has a margin of error generated by build-up welding or machining. The curvature may be obtained from an approximate shape. In addition, the portion that presses the forging material only has a convex portion having a curvature, and the curvature of the pressing portion is configured according to the present invention.

**[0029]** In the present invention, it is preferable that a curvature radius of a substantially semicircular convex portion in the finishing portion 4 is larger than a curvature radius of a substantially semicircular convex portion in the rough processing portion 3 by 10 mm or more. The reason for this is as follows. The forging material according to the present invention is a preform for a large turbine blade, and in the preform for a large (long) turbine blade, it is preferable that the contact area between the rough processing portion and the finishing portion is large. In addition, another reason is that, in a case where the curvature radius of the substantially semicircular convex portion in the finishing portion is large, a processing groove having a wide width can be easily formed. In order to prevent an overlap defect in a necked portion during hot-forging for stretching which is performed after hot forging for necking, it is preferable that the width of the processing groove formed by necking is large. In a case where a difference in curvature radius between the finishing portion and the rough processing portion is less than 10 mm, the effect cannot be sufficiently obtained. Therefore, the curvature radius of a substantially semicircular convex portion in the finishing portion 4 is adjusted to be larger than the curvature radius of the substantially semicircular convex portion in the rough processing portion 3 by 10 mm or more. The difference is preferably

15 mm or more.

**[0030]** As described above, the hot forging die 1 according to the present invention is suitable for necking. As shown in Fig. 2, a plurality of halved pressing portions 2 for necking may be formed in the longitudinal direction of the forging material. The reason for this is as follows. In a case where two or more processing grooves are formed by necking, it is advantageous to form a plurality of halved pressing portions 2 for necking in one die from the viewpoint of productivity. In particular, an alloy material used for a turbine blade is a difficult-to-work material. Therefore, it is preferable that forging is finished within the shortest possible time in a temperature range where hot forging is possible. The simultaneous formation of a plurality of grooves by necking is effective in a portion for forming a boss portion which is provided in a wing portion of a turbine blade.

**[0031]** The simultaneous formation of a plurality of grooves by necking can be realized by using a radial forging machine in combination with the hot forging die according to the present invention in which the contact area of the pressing portion gradually increases from a small area to a large area.

**[0032]** In the hot forging die having a structure shown in Fig. 2, similarly, the finishing portion is a portion having the same curvature radius which includes a position (bottom) shown in the cross-sectional view E-E (ranging from a position shown in a cross-sectional view F-F to a position shown in a cross-sectional view E-E).

**[0033]** After forging for necking, the forging material is stretched into a predetermined preform shape. A hot forging die 11 used in this case includes a stretching portion 7 that stretches the forging material. Regarding a pressing portion for stretching that is provided in the stretching portion 7, as shown in Fig. 3, the pressing portion is formed flat (flat in the longitudinal direction of the forging material 2 and curved such that the forging material 2 is inserted thereinto). The stretching portion 7 for stretching includes a pair of halved pressing portions 12 between which the forging material is interposed, in which each of the halved pressing portions 12 has a substantially semicircular convex shape which is continuous so as to surround the forging material, and each of the halved pressing portions 12 includes a substantially flat rough processing portion 13 and a finishing portion 14. The basic configuration is the same as that of the hot forging die suitable for necking. Likewise, two hot forging dies 11 for stretching shown in Fig. 3 are set as a pair. During the stretching of the forging material, the forging material is held and rotated by a holding mechanism included in a radial forging machine such that the pair of hot forging dies 11 for stretching cooperate together to reduce the diameter of the forging material (not shown). In addition, along with the rotation of the forging material, the held forging material moves in the longitudinal direction and is also stretched in the longitudinal direction.

**[0034]** Regarding the flat pressing portion of the hot forging die for stretching, it is preferable that the width of

the substantially flat pressing portion formed in the rough processing portion 13 is set to be narrow and the width of the pressing portion formed in the finishing portion 14 is set to be wider than that of the rough processing portion 13 such that the contact area is reduced for efficient stretching in the initial stage of forging and then a predetermined shape is obtained.

**[0035]** As described above, in the hot forging die 11 for stretching, the shape of the hot forging die is adjusted while stretching the forging material in the longitudinal direction. Therefore, the pressing portion becomes flat. In a case where the width of the flat pressing portion (the width in the longitudinal direction of the forging material) is excessively wide, a pressure required for forging is large. Therefore, it is preferable that the width of the flat pressing portion is adjusted to be suitable for a forging machine in consideration of the contact area such that the forging material can be efficiently stretched by impacting it once.

**[0036]** Next, a hot forging method of forming a preform for 50-inch turbine blade using the hot forging die according to the present invention will be described as an example.

**[0037]** Fig. 4 is a schematic diagram showing an example of a radial forging machine. The hot forging dies 1 shown in Fig. 1 are attached to the radial forging machine. Each of the hot forging dies 1 are provided on each of opposite surfaces to the forging material such that the forging material 21 is interposed between the hot forging dies 1. In Fig. 4, the forging material 21 is held in the radial forging machine. The forging material is heated to a predetermined hot forging temperature in a heating furnace (not shown) and is attached to the radial forging machine.

**[0038]** The heating temperature varies depending on the material of the forging material. For example, in a case where the material of the forging material is a Ni-based heat-resistant superalloy, the heating temperature is 950°C to 1150°C. In a case where the material of the forging material is a Ti alloy, the heating temperature is 800°C to 1000°C. In addition, in a case where the material of the forging material is a precipitation hardening stainless steel, the heating temperature is 900°C to 1200°C. In addition, the shape of the forging material is a rod shape. The rod-shaped forging material only has to be adjusted to a predetermined shape using a forging machine or a press machine. In a case where the forging material has a round rod shape, it is preferable that the diameter of the forging material is the same as the distance of the rough processing portions of the hot forging die 1 for necking.

**[0039]** Among the above-described forging materials, the forging material having a predetermined round rod shape is attached to the radial forging machine.

**[0040]** During the hot forging, the forging material is necked by rotating the heated forging material 21 and concurrently pressing the forging material using each of the halved pressing portions of the pair of two hot forging

dies 1 which are facing each other. The shape of the hot forging die for necking is as shown in Fig. 1. During necking, hot forging starts from the rough processing portions 3 of the hot forging die 1. The hot forging die according to the present invention has a shape in which the distance between the rough processing portions increases in a direction from the finishing portion 4 to the rough processing portions 3 and in which, when the two hot forging dies press the forging material, the forging material can be pressed in a continuous substantially semicircular convex shape. In addition, during initial necking, the forging material rotates at the same position (does not move in the longitudinal direction of the forging material).

**[0041]** Examples of a necking method include two methods. As a first method, a method in which the shape after completion of necking is emphasized will be described first.

**[0042]** In a case where hot forging starts from two directions opposite to each other, as shown in Fig. 6(A), predetermined positions of the forging material start to be pressed by the rough processing portions 3 first. Contact (forging) positions between the forging material 21 and the hot forging die during rough processing are indicated by arrows. As a result, the forging material is hot-forged in the two directions opposite to each other and, in the initial stage of forging, starts to be pressed by the rough processing portions formed in the two hot forging dies that cooperate together to forge the forging material. Thus, the number of positions where the forging material is pressed at the start of forging is four. In a case where necking starts at the four positions at the same time, the contact area is small, and thus a groove can be efficiently formed. By sequentially hot-forging the forging material toward the finishing portions, the shape of the forging material is adjusted to a predetermined shape in the finishing portions that are formed in the pair of hot forging dies. In the final stage of finishing, as shown in Fig. 6(B), the number of positions where the forging material 21 is pressed during hot forging in the bottoms of the finishing portions is two. That is, in the initial stage of necking, the four positions are forged (necked) using the pair of hot forging dies. During the adjustment of a final shape, the two positions are forged using the pair of hot forging dies. As a result, the shape of the forging material can be adjusted. In addition, the forging material can be efficiently formed in a final shape in the finishing portions 4 each having a convex portion having a larger curvature radius than the rough processing portions. Further, the final shape of the forging material can be adjusted to the bottom shape of the finishing portion indicated by an arrow. Therefore, this method is suitable in a case where the final finished shape is emphasized.

**[0043]** A second method is a method which is applicable to a case where the processing time is short.

**[0044]** In a case where hot forging starts from two directions opposite to each other, as shown in Fig. 7(A), predetermined positions of the forging material start to be pressed by the rough processing portions 3 first. Con-

tact (forging) positions between the forging material 21 and the hot forging die during rough processing are indicated by arrows. As a result, the forging material is hot-forged in the two directions opposite to each other and, in the initial stage of forging, starts to be pressed by the rough processing portions formed in the two hot forging dies that cooperate together to forge the forging material. Thus, the number of positions where the forging material is pressed at the start of forging is four. In a case where necking starts at the four positions at the same time, the contact area is small, and thus a groove can be efficiently formed. By sequentially hot-forging the forging material toward the finishing portions, the shape of the forging material is adjusted to a predetermined shape in the finishing portions 4 that are formed in the pair of hot forging dies.

**[0045]** As described above, in a region from the position shown in the cross-sectional view B-B to a position (bottom) shown in the cross-sectional view A-A, the curvature radius is substantially the same. Therefore, finishing is not performed in the bottoms of the finishing portions and can be finished in a state where the number of positions where the hot forging material is pressed during finishing is four as shown in Fig. 7(B). Even in this case, the forging material can be efficiently formed in a final shape in the convex finishing portion 4 having a larger curvature radius than the rough processing portion. In addition, since the number of positions where the hot forging material is pressed is four, necking can be finished within a short period of time. Thus, this method is suitable in a case where it is desired that the forging time is short.

**[0046]** In the method in which the forging time is emphasized, it is important to adjust the curvature radius (the curvature radius when seen from a direction perpendicular to the longitudinal direction of the forging material shown in Fig. 7) of the bottom (position shown in the cross-sectional view A-A) of the finishing portion to be less than the curvature radius of the diameter after necking. In this case, it is preferable that the bottom of the finishing portion is curved in order to avoid excessive stress concentration during hot forging.

**[0047]** Once necking is completed, the hot forging die 1 is replaced with the hot forging die 11 including the pressing portion for stretching. When the hot forging dies are replaced, the forging material is reheated to a predetermined forging temperature.

**[0048]** The replaced hot forging die 11 includes the stretching portion 7 including the pressing portion for stretching that stretches the forging material. The pressing portion for stretching has a shape shown in Fig. 3. When the hot forging die 11 including the pressing portion for stretching is seen from the longitudinal direction of the forging material, the shape of the pressing portion is the same as that of the hot forging die 1 for necking shown in Fig. 6(A). Therefore, in a case where hot forging starts from two directions opposite to each other, predetermined positions of the forging material start to be pressed

by the rough processing portions 13 first. As a result, the forging material is hot-forged in the two directions opposite to each other and, in the initial stage of stretching (forging), starts to be pressed by the rough processing portions formed in the two (the pair of) hot forging dies that cooperate together to forge the forging material. Thus, the number of positions where the forging material is pressed at the start of forging is four. In a case where stretching starts at the four positions at the same time, the contact area is small, and thus the forging material can be efficiently stretched. The forging material is sequentially moved in the longitudinal direction of the forging material while being intermittently rotated by the radial forging machine, and then is sequentially hot-forged toward the finishing portions. As a result, the shape of the forging material is adjusted to a predetermined shape in the finishing portions that are formed in the pair of hot forging dies.

**[0049]** That is, in the final stage of finishing, as shown in Fig. 6(B), the number of positions where the forging material is pressed during hot forging in the finishing portions 14 is two. The method of adjusting the final shape to the bottom shape of the finishing portion is suitable in a case where the final finished shape is emphasized.

**[0050]** In addition, in order to reduce the hot forging time during hot forging using the pressing portion for stretching, the number of positions where the hot forging material is pressed from the initial stage to the final stage of hot forging is adjusted to four as shown in Fig. 7. As a result, the forging material can be stretched within a short period of time.

**[0051]** In addition, the hot forging die including the pressing portion for stretching can be made to have a shape shown in Fig. 8. In the hot forging die 11 shown in Fig. 8, a concave portion 8 is formed in a region from the bottom in the width of the finishing portion 14 (the width in the longitudinal direction of the forging material) to the rough processing portion. Due to the concave portion 8, the pressing portion of the finishing portion is divided into two areas. By forming one or more concave portions in the width of the finishing portion 14 to divide the pressing portion of the finishing portion into two or more areas, the forging material can be more reliably prevented from being bent during stretching. In a case where the forging material is hot-forged using the hot forging die shown in Fig. 8, the final stage of forging is performed in the bottom of the finishing portion shown in the cross-sectional view A-A. When the forging material is pressed, there are two portions including: a pressed portion that is pressed by the finishing portion; and a portion that is not pressed by the finishing portion and is adjacent to the portion pressed by the finishing portion. A part of the pressed portion flows to the non-pressed portion such that the cross-section of the forging material is slightly elliptical. The elliptical forging material is likely to be bent during forging. However, in the structure of the hot forging die shown in Fig. 8, the pressing portion (finishing portion) is divided by the concave portion.

Therefore, the forging material is intermittently rotated by radial forging in the initial pressing portion and is finished in the next pressing portion. At this time, four portions in total are pressed in the structure shown in Fig. 8. Therefore, as described above, an elliptical shape and a bent shape can be corrected in the pressing portion. By forming the concave portion at positions including the bottom of the finishing portion (the position in contact with the straight line A-A in Fig. 8), the effect of preventing bending can be exhibited as much as possible.

**[0052]** This way, the forging material can be continuously hot-forged into a predetermined preform shape by using the same radial forging machine not only for necking but also for stretching. Therefore, unlike the related art, it is not necessary to perform stretching using a separate forging machine after using a jig for necking. That is, a troublesome process can be reduced. Thus, although the number of times of reheating is reduced, a preform for a high-accuracy turbine blade can be manufactured.

**[0053]** According to the present invention, even a difficult-to-work material used for a turbine blade can be easily necked using a radial forging machine. In addition, according to the novel hot forging method using a radial forging machine, the number of times of reheating a forging material can be significantly reduced, the productivity can be improved, and this method is extremely effective in power saving.

## Examples

### (Example 1)

**[0054]** The hot forging die 1 according to the present invention shown in Fig. 2 was prepared.

**[0055]** A necking portion 5 of the prepared hot forging die 1 for necking includes a pair of halved pressing portions between which the forging material is interposed, in which each of the halved pressing portions has a convex portion having a substantially semicircular cross-section which is continuous so as to surround the forging material, and each of the halved pressing portions includes a rough processing portion and a finishing portion having a convex portion having a larger curvature radius than the rough processing portion. The curvature radius of the necking portion 5 gradually changes, in which the curvature radius of the substantially semicircular convex portion of the rough processing portion 13 is 30 mm, and the curvature radius of the substantially semicircular convex portion of the finishing portion 14 is 50 mm.

**[0056]** In addition, regarding the pressing portion for stretching provided in the stretching portion 7 of the hot forging die 11 that stretches the forging material after necking, the pressing portion is formed flat, and the shape thereof is as shown in Fig. 3. The stretching portion 7 for stretching includes a pair of halved pressing portions 12 between which the forging material is interposed, in which each of the halved pressing portions 12 has a sub-

stantially semicircular convex shape which is continuous so as to surround the forging material, and each of the halved pressing portions 12 includes a substantially flat rough processing portion 13 and a finishing portion 14. The width of the pressing portion for stretching gradually changes, in which the width of the rough processing portion 13 is 50 mm, and the width of the finishing portion 14 is 100 mm. Stretching was performed using a hot forging die having a shape in which a final shape was emphasized.

**[0057]** The above-described two hot forging dies were set as a pair, and the pair of hot forging dies were attached to a radial forging machine.

**[0058]** A forging material for a 50-inch turbine blade was heated in a heating furnace heated to 950°C. The forging material was formed of a titanium alloy, in which the diameter was  $\phi 200$  mm and the length was 1100 mm.

**[0059]** The forging material was extracted from the heating furnace and started to be hot-forged in the radial forging machine. The forging material was held by a manipulator.

**[0060]** During the hot forging, the forging material was necked by rotating the heated forging material 21 and concurrently pressing the forging material using each of the halved pressing portions of the pair of two hot forging dies 1 which were facing each other. During initial necking, the forging material was hot-forged into a predetermined shape while rotating the forging material at the same position (not moving in the longitudinal direction of the forging material). As shown in Fig. 2, a plurality of halved pressing portions 2 for necking were formed in one die, and two portions were necked at the same time using this die.

**[0061]** After completion of necking, the hot forging die was replaced with the hot forging die 11 including the pressing portion for stretching. At this time, the forging material was extracted from the radial forging machine and was reheated to a predetermined forging temperature. After completion of the replacement with the hot forging die 11 including the pressing portion for stretching, the forging material was attached to the radial forging machine again and was hot-forged using the pressing portion for stretching. The forging material was intermittently rotated by the radial forging machine and was sequentially moved in the longitudinal direction such that the shape thereof was adjusted to a predetermined shape. As a result, the forging material was hot-forged into a preform shape. A preform 22 after hot forging had a shape shown in Fig. 7 which was suitable for forming a root portion, a wing portion, or a boss portion. In the preform after hot forging, a preform such as an overlap defect did not occur.

(Example 2)

**[0062]** In Example 2, the effect of the hot forging die shown in Fig. 8 was verified. The same hot forging die for necking as in Example 1 was used.

**[0063]** In Example 2, the effect of the hot forging die 11 shown in Fig. 8 was verified. In the hot forging die shown in Fig. 8, the stretching portion 7 for stretching includes a pair of halved pressing portions 12 between which the forging material is interposed, in which each of the halved pressing portions 12 has a substantially semicircular convex shape which is continuous so as to surround the forging material, and each of the halved pressing portions 12 includes a substantially flat rough processing portion 13 and a finishing portion 14. The width of the pressing portion for stretching gradually changes, in which the width of the rough processing portion 13 is 50 mm, and the width of the finishing portion 14 is 100 mm. A concave portion having a width of 80 mm was formed at the center of the finishing portion, and the number of pressing portions in the finishing portion was 2. The width of each of the two divided pressing portions was 270 mm. The same hot forging die for necking as in Example 1 was used.

**[0064]** A forging material for a 50-inch turbine blade was heated in a heating furnace heated to 950°C. The forging material was formed of a titanium alloy, in which the diameter was  $\phi 200$  mm and the length was 1100 mm.

**[0065]** The forging material was extracted from the heating furnace and started to be hot-forged in the radial forging machine. The forging material was held by a manipulator.

**[0066]** During the hot forging, the forging material was necked by rotating the heated forging material 21 and concurrently pressing the forging material using each of the halved pressing portions of the pair of two hot forging dies 1 which were facing each other. During initial necking, the forging material was hot-forged in a predetermined shape while rotating the forging material at the same position (not moving in the longitudinal direction of the forging material). As shown in Fig. 3, a plurality of halved pressing portions 12 for necking were formed in one die, and two portions were necked at the same time using this die.

**[0067]** After completion of necking, the hot forging die was replaced with the hot forging die 11 of Fig. 3 including the pressing portion for stretching. At this time, the forging material was extracted from the radial forging machine and was reheated to a predetermined forging temperature. After completion of the replacement with the hot forging die 11 including the pressing portion for stretching, the forging material was attached to the radial forging machine again and was hot-forged using the pressing portion for stretching. The forging material was intermittently rotated by the radial forging machine and was sequentially moved in the longitudinal direction such that the shape thereof was adjusted to a predetermined shape. As a result, the forging material was hot-forged into a preform shape. Finally, the hot forging die was replaced with the hot forging die 11 shown in Fig. 8, and the forging material was finished using 10-pass radial forging. A preform 22 after hot forging had a shape shown in Fig. 5 which was suitable for forming a root portion, a

wing portion, or a boss portion. In the preform after hot forging, a preform such as an overlap defect did not occur. Regarding the bending of the preform having a total length of about 1500 mm, it was verified that bending of about 5 mm was suppressed by comparing the preform obtained in Example 2 to the preform obtained in Example 1.

**[0068]** With the method according to the present invention, even a difficult-to-work material used for a turbine blade or the like can be easily stretched using a radial forging machine. In addition, a forging material can be hot-forged and necked into a predetermined preform shape using a radial forging machine. Therefore, unlike the related art, a troublesome process such as use of a jig for necking can be reduced. Thus, although the number of times of reheating is reduced, a preform for a high-accuracy turbine blade can be manufactured.

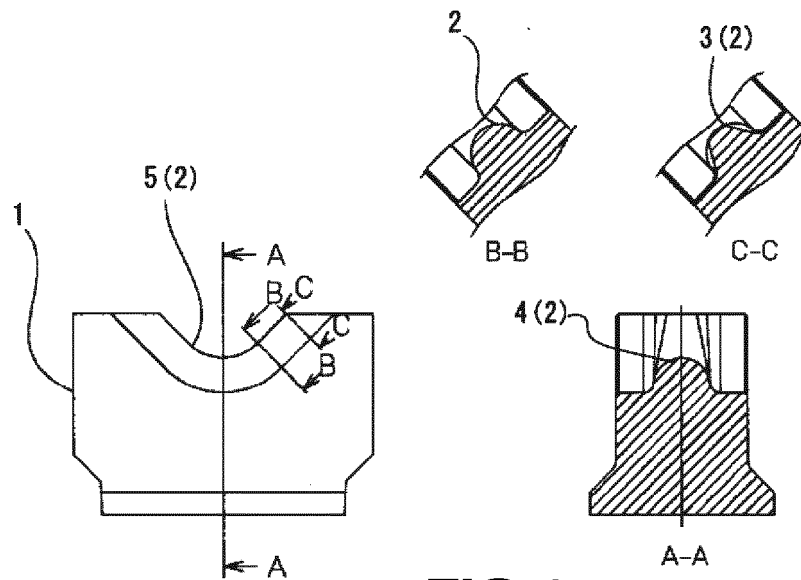
## Claims

1. A hot forging die for hot-forging a rod-shaped forging material by radial forging, the hot forging die comprising a pair of halved pressing portions for interposing the forging material between the pair of the halved pressing portions, each of the halved pressing portions being a convex portion having a substantially semicircular cross-section, the convex portion being continuous so as to surround the forging material, wherein each of the halved pressing portions includes a rough processing portion and a finishing portion being a convex portion having a larger curvature radius than the rough processing portion.
2. The hot forging die according to claim 1, wherein each of the halved pressing portions includes a gradual change portion in which a curvature radius of the halved pressing portion gradually increases in a direction from the rough processing portion to the finishing portion.
3. The hot forging die according to claim 1 or 2, wherein a curvature radius of the convex portion having the substantially semicircular shape in the finishing portion is larger than a curvature radius of the convex portion having a substantially semicircular shape in the rough processing portion by 10 mm or more.
4. The hot forging die according to any one of claims 1 to 3, wherein the halved pressing portions has a pressing portion for necking.
5. The hot forging die according to claim 4, wherein a plurality of the pressing portions for necking are provided in a longitudinal direction of the forging material.

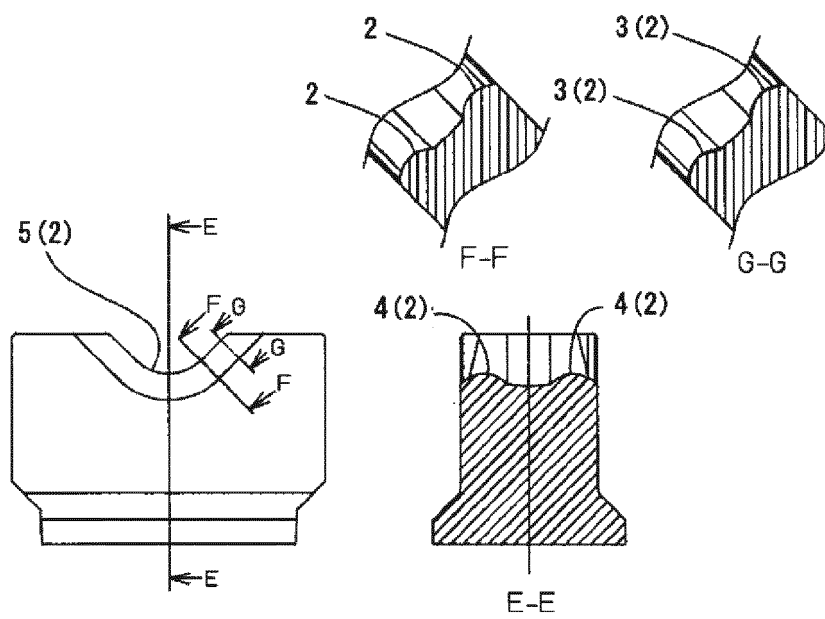
6. A hot forging method for hot-forging a rod-shaped forging material by radial forging by using a hot forging die comprising a pair of halved pressing portions for interposing the forging material between the pair of the halved pressing portions, each of the halved pressing portions being a convex portion having a substantially semicircular cross-section, the convex portion being continuous so as to surround the forging material, each of the halved pressing portions including a rough processing portion and a finishing portion being a convex portion having a larger curvature radius than the rough processing portion, wherein the hot forging method comprising:

a forging material heating step of heating the forging material to a hot forging temperature; and  
a hot forging step of necking the forging material by rotating the heated forging material and concurrently pressing the forging material with the hot forging die at the pair of the halved pressing portions facing each other.

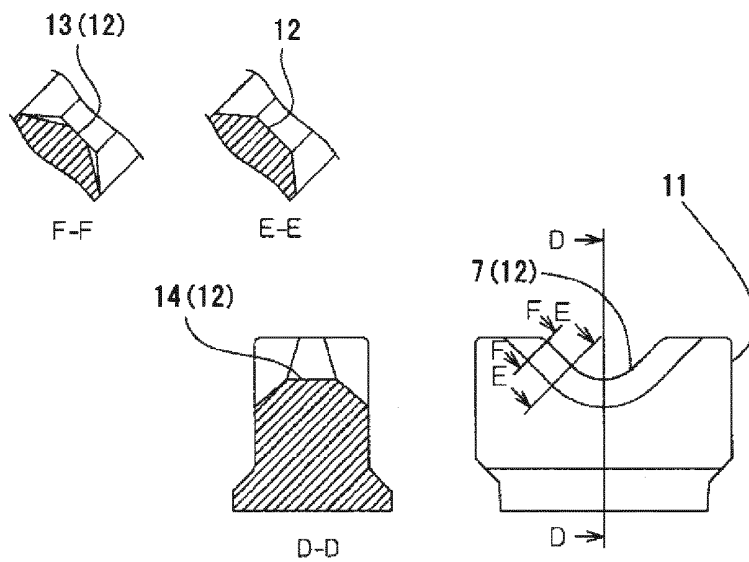
7. The hot forging method according to claim 6, wherein the rod-shaped forging material is formed of a Ni-based heat-resistant superalloy or a Ti alloy.
8. The hot forging method according to claim 6 or 7, wherein the forging material is a preform for a turbine blade.



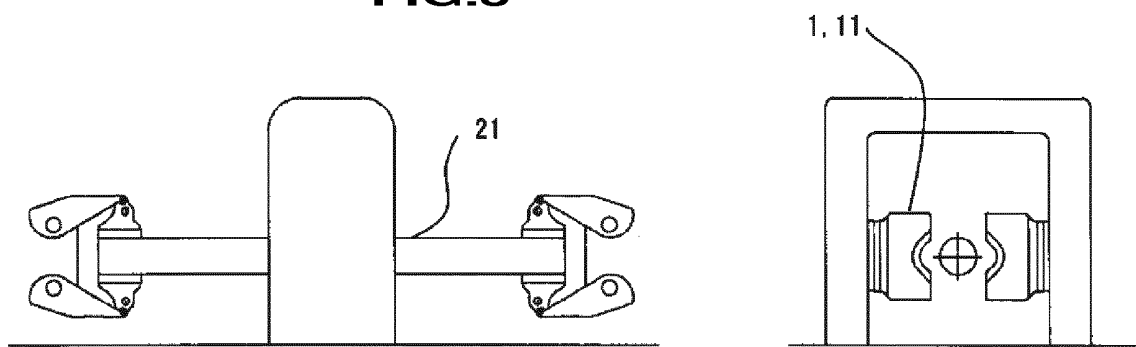
**FIG. 1**



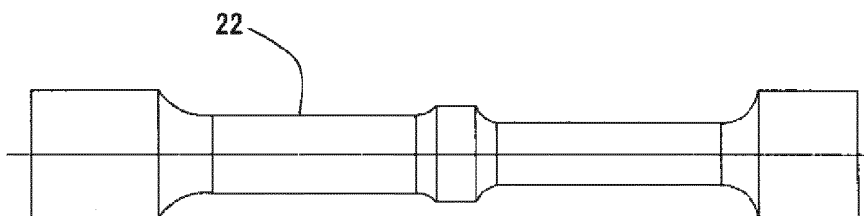
**FIG. 2**



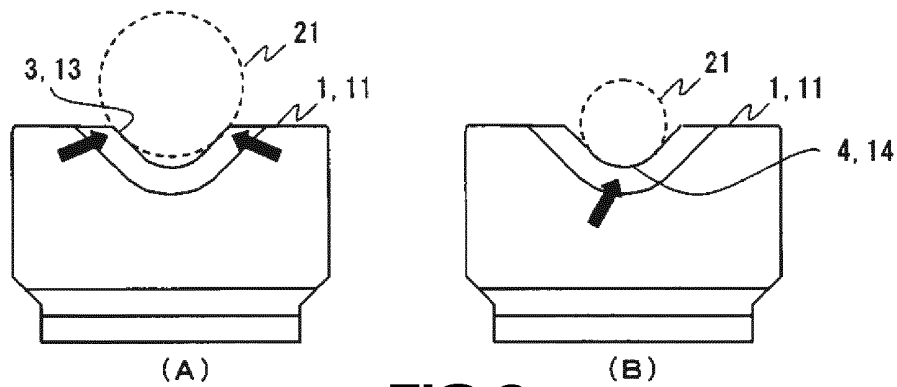
**FIG. 3**



**FIG. 4**



**FIG. 5**



**FIG. 6**

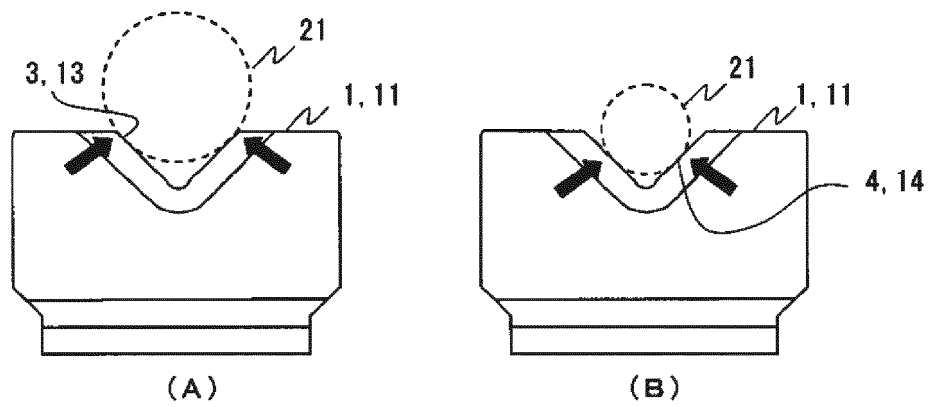


FIG. 7

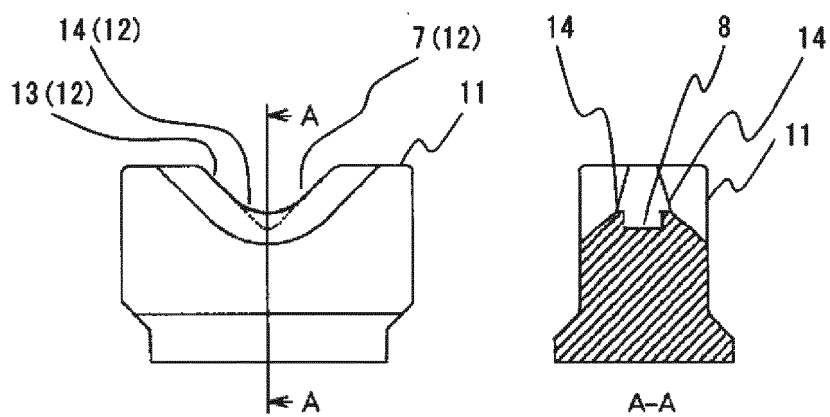


FIG. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/060732

## A. CLASSIFICATION OF SUBJECT MATTER

B21J13/02(2006.01)i, B21J5/00(2006.01)i, B21K3/04(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B21J13/02, B21J5/00, B21K3/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                             | Relevant to claim No. |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | JP 53-5056 A (Kobe Steel, Ltd.),<br>18 January 1978 (18.01.1978),<br>page 3, upper left column, line 9 to page 5,<br>upper left column, line 20; fig. 2 to 6<br>(Family: none) | 1-8                   |
| A         | JP 7-185725 A (Daido Steel Co., Ltd.),<br>25 July 1995 (25.07.1995),<br>paragraphs [0014] to [0017]; fig. 1 to 3<br>(Family: none)                                             | 1-8                   |

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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Date of the actual completion of the international search

26 April 2016 (26.04.16)

Date of mailing of the international search report

10 May 2016 (10.05.16)

Name and mailing address of the ISA/

Japan Patent Office

3-4-3, Kasumigaseki, Chiyoda-ku,

Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/060732

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                | Relevant to claim No. |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | JP 56-1236 A (Nippon Steel Corp.),<br>08 January 1981 (08.01.1981),<br>page 2, lower right column, line 9 to page 5,<br>lower left column, line 14; fig. 11<br>& US 4407056 A<br>column 3, line 3 to column 7, line 24; fig. 11<br>& DE 2940473 A | 1-8                   |
| A         | JP 55-136535 A (Sumitomo Metal Industries,<br>Ltd.),<br>24 October 1980 (24.10.1980),<br>page 2, upper left column, line 15 to lower<br>right column, line 11; fig. 1 to 4<br>(Family: none)                                                      | 1-8                   |

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**REFERENCES CITED IN THE DESCRIPTION**

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- JP 60250843 A [0005] [0006]