March 5, 1968 SATORU MITO ET AL 3,371,908

TURBINE BLADING COMPONENTS AND PROCESS OF PRODUCING THE SAME

Filed Nov. 1, 1966 3 Sheets-Sheet 1

FIG. 1

PRIOR ART

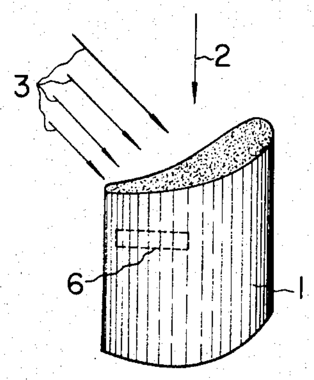

FIG. 2

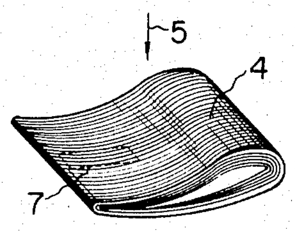

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FIG. 3

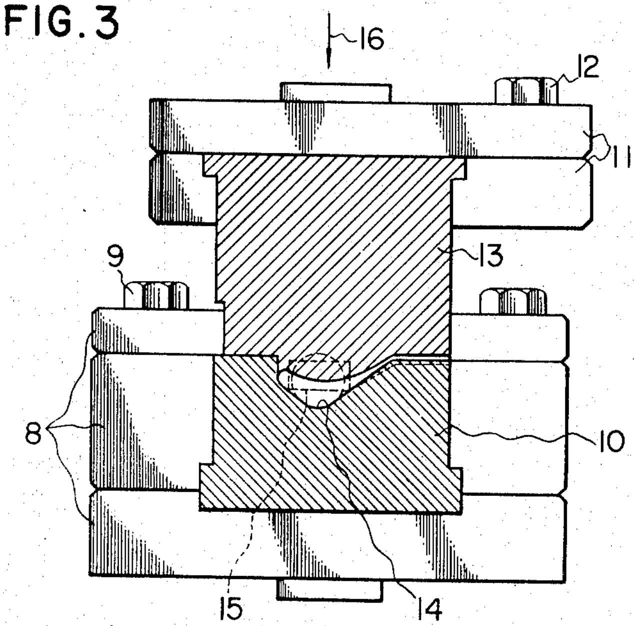


FIG. 4

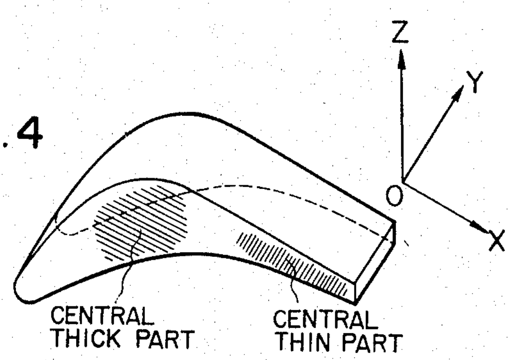
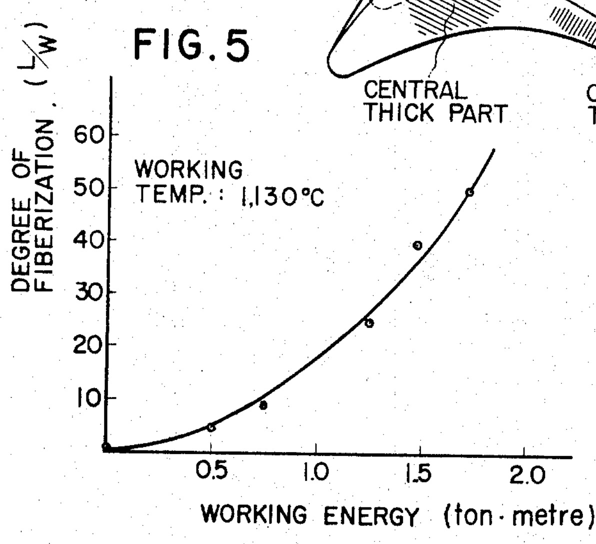


FIG. 5



BLANK COMPOSITION (wt. %)	
C	0.05
Si	0.03
Mn	0.38
P	0.017
S	0.011
Cr	13.39
Ni	0.15
Al	0.15
Fe	Remainder

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FIG. 6

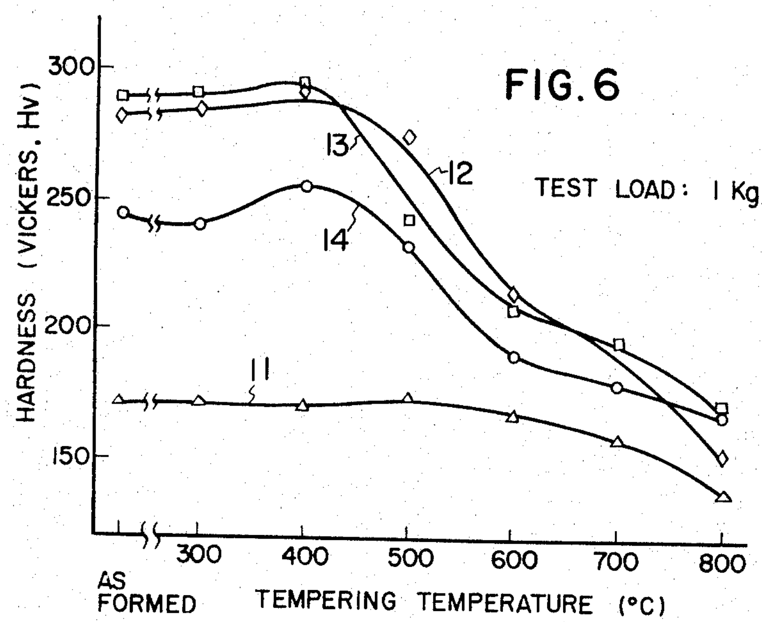
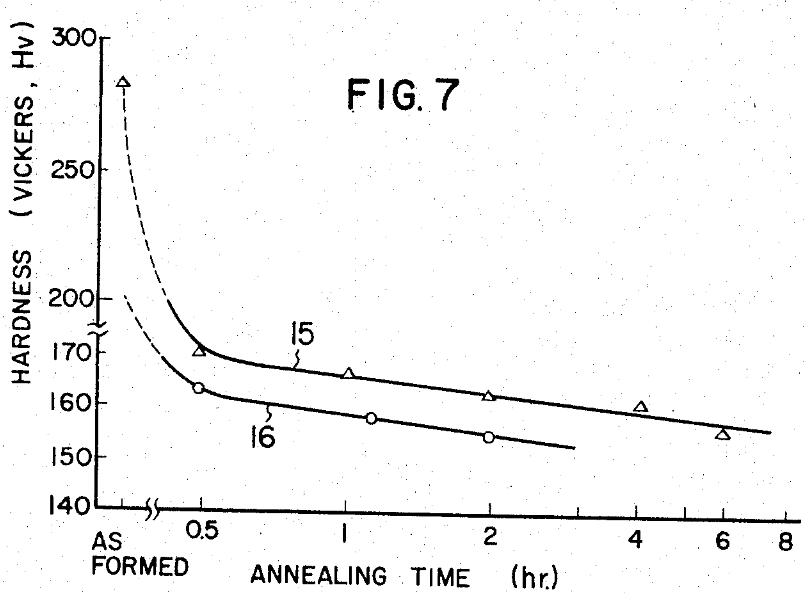


FIG. 7



3,371,908

TURBINE BLADING COMPONENTS AND PROCESS OF PRODUCING THE SAME

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Filed Nov. 1, 1966, Ser. No. 591,330
Claims priority, application Japan, Nov. 2, 1965, 40/66,922
3 Claims. (Cl. 253—77)

ABSTRACT OF THE DISCLOSURE

A turbine blade for use in a turbine having a fibrous crystalline structure on all of the working surfaces of its body sections no less than a fiberization of 10 and existing along an entire longitudinal axis of the blade. The fiberization is oriented in a direction, on the body of the blade, substantially parallel to a direction of flow of the operating or working fluid relative to the blade.

This invention relates to turbine components and, more particularly, to forged blading components in turbines such as stationary blades or nozzles and moving blades and to a process of producing the same.

The nozzles and blades of steam on gas turbines are, during operation, subjected on the entire surfaces thereof to steam or gas flow of high velocity and temperature, and therefore tend, after a prolonged operation, to produce creep which often leads to turbine failure. Especially thin portions of the turbine nozzles and blades are the weakest and tend to be deformed by bending moment imposed thereon. Such thin portions are also most liable to deteriorate when there are segregations of the components of the alloy of which they are made and when there exist non-metallic components intermixed in the alloy.

A recently developed new method of making the turbine blades utilizes a forging process employing a super-high speed motion. According to this method, the metal blanks are prepared by forcing the metal through an extruding die, and the blanks thus obtained are subjected to the said forging process.

A turbine blade, for example, produced by this new method has a fibrous structure which is disadvantageous for imparting strength to the blade as will be described more fully hereinafter.

A principal object of this invention is to eliminate the above mentioned drawback.

A more specific object of this invention is to provide turbine components such as turbine blades and nozzles which are made to resist stresses imposed thereon during operation by imparting thereto a mechanically anisotropic character and a "degree of fiberization" which affords a crystal structure of the components resistant to the force of the operating fluid at high velocity and temperature, and to provide a process of producing the same.

The term "degree of fiberization" as aforementioned and as will hereinafter be used designates the ratio of the length L to the width W (L/W) of a fibrous crystal in the crystal structure of a metal material.

According to the present invention, briefly stated, there is provided a turbine component such as a turbine blade or nozzle which, at least at thin portions thereof, has a fibrous crystal structure developed substantially parallel to the direction of flow of the operating fluid, such as high-temperature pressurized steam or gas, flowing relative to the component. This crystal structure extends in and on the side surface of the component and includes fibrous crystals having a degree of fiberization of 10 or more.

The turbine blades according to the invention include a body having a leading section having a thickest cross section of the blade and a trailing section of thinner cross section. The body has a fibrous crystalline structure from section to section and continuous from one section to the other with the sections merging smoothly.

According to the present invention there is further provided a process of producing turbine components of the above described character.

The nature, principle, and details of the invention will be more clearly apparent from the following detailed description, when read in conjunction with the accompanying illustrations.

In the illustrations:

FIG. 1 is a fragmentary perspective showing a fragment of a turbine nozzle produced by a known method and indicating the fibre direction of the crystalline structure thereof;

FIG. 2 is a fragmentary perspective view showing a fragment of a turbine blade produced by the method of the present invention and indicating the fibre direction of the crystalline structure thereof;

FIG. 3 is an elevational view, partly in section, of an example of a forging press which may be used to carry out the process of the invention;

FIG. 4 is a perspective view serving to assist in explaining the results of a test carried out to determine the mechanical properties of the final products;

FIG. 5 is a graph showing the relation between "degree of fiberization" and working energy used for working blanks;

FIG. 6 shows characteristic curves indicating the relation between tempering temperature and hardness of products; and

FIG. 7 shows characteristic curves showing the relation between hardness and annealing time.

FIG. 1 shows a fragmentary view, in perspective, of a turbine blade finally obtained by the aforementioned known new method. According to this method, the turbine nozzle generally indicated by reference numeral **1** has a fibrous crystal structure developed in the direction of the arrow **2**, that is, in the direction of extrusion. In this blade, the direction in which the operating fluid strikes against it with greatest force corresponds to that of the arrows **3**. Accordingly the direction of the stress imposed on the blade by the operating fluid is not the same as that of the fibres of the crystal structure but is substantially transverse to the same. This fact is one of the reasons for which a considerable increase in the strength of the blade cannot be expected in spite of the many fibrous crystals developed in the blade.

Referring now to FIG. 2, the invention will be described more in detail. In FIG. 2, reference numeral **4** designates a turbine blade or nozzle component according to the invention. In order to obtain the blade or nozzle **4**, a metal blank is heated to a temperature at which the blank is capable of undergoing plastic deformation. This heated blank is stamp forged in the direction of the arrow **5** to a desired shape to produce a fibrous crystal structure developed in parallel condition and extending at least at thin portions of the forged component and in and on the site surfaces of the same. In this case, the direction of the fibres of the structure must be substantially transverse to the direction of forging as shown by the arrow **5**, and the forging operation must be performed to produce a fibrous crystal structure having a degree of fiberization of 10 or more.

It is well known that the metal will be increased in strength if it is subjected to high plastic working, and that when the metal is composed of an aggregate structure of fibrous crystals, the strength of the metal is at a remarkably high value along the direction of the fibres. This is considered to be due to the fact that the crystal grain boundaries, intermixed non-metallic phases, segregated phases, etc., are caused to be arranged or directed in the same direction as the crystal fibres with the resultant elimination of their adverse effect on the property of the metal. Such an increase in strength and improvement in crystal structure caused by the high degree of plastic working are usually obtained through plastic working, such as rolling, drawing, extrusion, forging and so on at a temperature below the recrystallization temperature. However, such an increase and improvement may be obtained to some degree even at a temperature above the recrystallization temperature, if the working is accomplished in a time which is sufficiently short so as not to permit development of the crystals which arises after the working, and if there exist impurities which restrain free development of the crystals. The degree of fiberization is, however, between about 2 and 3 when extend forging is carried out repeatedly at a temperature above the recrystallization temperature, and the degree of fiberization, reaches only between about 3 and 5 even by stamp forging. In such ranges of the degree of fiberization, the anisotropy in mechanical strength is low, and no particular tendency for increased strength in the direction of the fibrous crystals can be observed.

In order to increase the mechanical strength, a high degree of plastic working which makes it possible to obtain a degree of fiberization of 10 or more is necessary. For this purpose, extend forged metal worked to a low degree of fiberization is further subject to a high degree of working, such as rolling and forging, to form a structure of high degree of fiberization in and on the whole or partial surface thereof, the fibrous structure extending parallel and positioned in and on the side surfaces of the thin portions of the metal.

To impart a high degree of fiberization in the working process, the amount of working in one operation may be reduced and the repeated number of the working operations may be increased. On the other hand, in the type of working which can accomplish a great amount of working in an instant, such as explosion working and high-velocity impact working, it is possible to develop a sufficient degree of fiberization by a single working process. The reason for which the degree of fiberization has been limited to ten or more in the invention is that the properties of the metal cannot be improved to a satisfactory degree below the limiting value of ten.

In practice, the following type of stamp working would be preferable in order to forge turbine blades or nozzles having a fibrous crystal structure which is directed parallelly in substantially transverse direction to that of the forging and positioned in and on the side surfaces of the thin portions with a degree of fiberization developed to a satisfactory value.

(a) Closed type [plane type and curved type (biting type, stepped type, guide pin type)]
(b) Open type
(c) One-heating type

Working of the type such as extruding, swaging and telescoping are not suitable.

The working ratio in a single operation, as expressed

by the reduction ratio relative to the blank size, is preferably above 75–80% for the thin portions the strength of which is to be improved. The working speed is preferably above 8 metres per second; below this value the plastic flow will be in an unsatisfactory condition.

The forged articles thus obtained may be annealed to remove strain at a temperature of 400–800° C.

As shown in FIG. 4, the turbine nozzle on blade has an unsymmetrical shape with the thin portion thereof having a thickness of, for example, about two millimetres. Therefore, the strains resulting from the working are unevenly distributed, the speeds of cooling after the working are different throughout the nozzle or blade, and the plastic flow generated in the blank due to the working is in a complex condition.

A test was carried out for the purpose of determining whether there are obtained strengthened products by the forging and of determining the distribution of mechanical properties in the products and the anisotropic characters thereof. In the test, forged nozzles without annealing and those with annealing were used. The following Table I shows the results of the test.

TABLE I

Treating condition	Positions tested	Directions of tension	Tensile Strength, kg./mm.^{2}	Strength, 0.1% yield, kg./mm.^{2}	Elongation, Percent
Forged at 1,200° C. without annealing	End of thin portion	X	91.0	60.3	4.5
		Y	89.3	54.7	5.8
	Center of thick portion		77.7	48.9	5.6
Forged at 1,000° C. without annealing	End of thin portion	X	94.3	61.6	5.5
		Y	96.6	69.8	4.2
	Center of thick portion	X	88.9	56.1	3.6
Forged at 1,200° C. with annealing at 800° C. for 30 minutes.	End of thin portion	Y	52.8	35.5	13.8
	Center of thick portion	X	50.1	30.6	22.1
Forged at 1,000° C. with annealing at 800° C. for 30 minutes.	End of thin portion	X	48.5	25.8	20.7
	Center of thick portion	X	48.7	26.3	20.5

The standard for the quality of turbine nozzle components defines the impact strength required, while it is known that the degree of strengthening due to heat treatment is best revealed in the impact tests.

For this reason, three kinds of test pieces were respectively taken from the central portions of three kinds of forged nozzles, the first one being naturally air cooled after forging, the second one annealed at 800° C. for an hour after the natural air cooling, and the third one slowly cooled in a condition embedded in a mass of rice plant ash. These test pieces were respectively cut to correspond to the JPS (Japanese Industrial Standard) No. 3 test piece and tested at room temperature in the direction of the arrow Y to determine the values of impact strength. The following Table II shows the results of the test.

TABLE II

Condition	Impact Strength, kg.-m./cm.^{2}	Fracture due to brittleness
Air cooled after working	13.0	Existed somewhat.
Slowly cooled in a mass of rice plant ash after working.	9.2	Existed.
Annealed at 800° C. for an hour after working and thereafter air cooled.	27.7	Did not exist.
Annealed at 800° C. for an hour after working and thereafter slowly cooled in a mass of rice plant ash.	24.9	Do.

The products from which the test pieces used in the above test were taken were not worked to a very great extent, and some of them presented fractures due to brittleness in the worked state perhaps because of their being taken perpendicularly to the working direction. These test pieces, however, exhibited improved elongation after annealing treatment.

FIG. 5 illustrates changes of degree of fiberization due to working energy. The degree of fiberization was measured with regard to the thin portion of turbine nozzle forgings which were obtained by heating blanks up to 1,130° C. and thereafter stamp forging the heated blanks at the different values of working energy respectively shown in FIG. 6. It will be noted from FIG. 6 that the degree of fiberization increases with increase in working energy.

FIG. 6 illustrates a graph which shows changes of hardness relative to tempering temperature, and hardness being measured with regard to turbine nozzle forgings which were prepared by heating blanks to 900–1,200° C., forging the heated blank, and thereafter annealing the same at different temperatures for 30 minutes. In this figure, the numeral **11** designates a curve for 900° C. forging, **12** a curve for 1,000° C. forging, **13** a curve for 1,100° C. forging and **14** a curve for 1,200° C. tempering. It will be seen from the graph that high values of hardness can be obtained if the forged products are heated to a temperature between 1,000° C. and 1,200° C.

FIG. 6 illustrates a graph which shows changes of hardness with annealing time, the hardness being measured with regard to turbine nozzle forgings which were prepared by forging the blanks and thereafter annealing the same at 800° C. for a time ranging from 0.5 to 6 hours. In the graph, the numeral **15** designates a curve with regard to a specimen which was air cooled after forging and further subjected to 800° C. annealing, and the numeral **16** a curve with regard to a specimen which was annealed at 800° C. immediately after the forging. It will be noted from the graph that the hardness can be made greater if the forged product is cooled and thereafter annealed at 800° C.

As above described, there are two processes of annealing turbine components, one consisting of cooling the forged products down to room temperature and thereafter annealing the same, another consisting of annealing the hot forged products immediately after the forging. Comparing both processes, the former can produce somewhat higher hardnesses, while the latter is preferable on the point of thermal economy. Again comparing the processes, there seems to be an essential difference whereby the former includes martensitic transformation and the latter includes annealing which is carried out without accompanying substantial quenching.

In this respect, changes in mechanical properties caused by the annealing treatment were studied. According to the study, it has been found that the latter is faster in softening due to annealing and has the advantage that the crystalline structure is made more uniform and finer.

Accordingly, from the view point of quality of metal such a process will be advantageous in that the annealing treatment is effected immediately after the forging operation, and one heat system of heat treatment will also be advantageous. The process just mentioned also has the advantage of the trimming operation required after the process being made easier.

In order to indicate still more fully the nature and utility of the invention, the following example of embodiment thereof and example of test results are set forth, it being understood that this example of embodiment of the invention is presented as illustrative only and that it is not intended to limit the scope of the invention.

A metal plate blank having a size of 55 x 42 x 16 mm. and consisting of 12.47 parts of Cr, 0.46 part of Al, 0.54 part of Mn, 0.12 part of Si, 0.07 part of C and the remainder of Fe, all by weight, was heated to and maintained at 1,000° C. for 30 minutes and thereafter put in a forging press as shown in FIG. 3. The press comprises a pair of upper and lower dies **13** and **10**, the upper die **13** being rigidly clamped between holders **11** by means of bolts **12** extending therethrough, and the lower die **10** being similarly clamped between holders **8** by means of bolts **9** extending therethrough. The upper and lower dies have on and in the opposed surfaces thereof a protrusion and a recess, respectively, which cooperate to define a forging cavity **14** corresponding to the shape of forgings to be produced. The heated blank **15** was put in this cavity

14 and forged to the shape of the blade **4** as shown in FIG. 2 in a single operation by a high-speed forging machine. Thus, a fibrous crystal structure was obtained having a degree of fiberization of 20. In this state, α-crystal grains are extended in a slender condition together with a pearlitic structure.

To test the mechanical strength of this structure, test pieces were respectively taken from the portions as shown by the dotted lines **6** and **7** of FIGS. 1 and 2. These test pieces which had the dimensions of 1.2 mm. x 1.5 mm. x 13 mm. were subjected to a tensile test and a creep rupture test at room temperature on a Chevenard type micromachine and on a single type creep rupture test machine, respectively.

The following Table III shows a comparison of the results of the tests on these test pieces with those of conventional turbine components worked by the high-speed trusion process.

TABLE III

	Tensile strength (kg./mm.²)
Blank	55
Conventional	87
This invention	100

The Table IV shows the result of a creep rupture test carried out at 500° C. under a load of 25 kg./cm.².

TABLE IV

	Rupture time
Blank	7 minutes.
Conventional	2 hours.
This invention	9 hours and 40 minutes.

It should be understood, of course, that the foregoing disclosure relates to only a preferred embodiment of the invention and that it is intended to cover all changes and modifications of the example of the invention herein chosen for the purposes of the disclosure, which do not constitute departures from the spirit and scope of the invention as set forth in the appended claims.

What we claim is:

1. A turbine blade for use in a turbine in which it is subjected to forces applied thereto by an operating fluid comprising a body having a leading section of thickest cross section and a trailing section of thinner cross section, said body comprising a fibrous crystalline structure having the same fibrous crystalline orientation on all of the working surfaces of the body sections and to at least some depth thereof, said orientation being oriented in a direction on said body substantially parallel to a direction of flow of said operating fluid relative to said blade when said blade is in operation in said fluid, and said fibrous crystalline structure having a minimum degree of fiberization of 10 and existing along an entire longitudinal axis of said blade.

2. A turbine blade according to claim 1, in which said blade has a longitudinal axis and said orientation is substantially normal to said longitudinal axis.

3. A turbine blade according to claim 1, in which said sections merge smoothly into each other and said fiberization continues from one section to the other section.

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