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METHOD OF FORMING SUPERALLOYS

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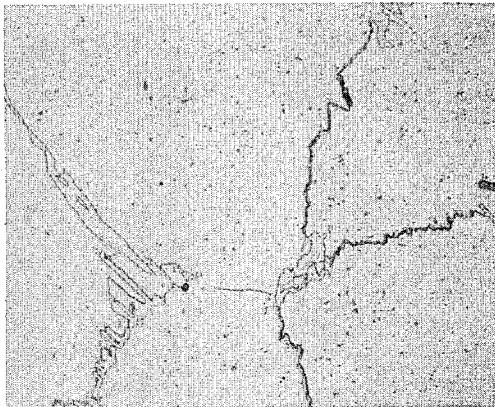


FIG. 3

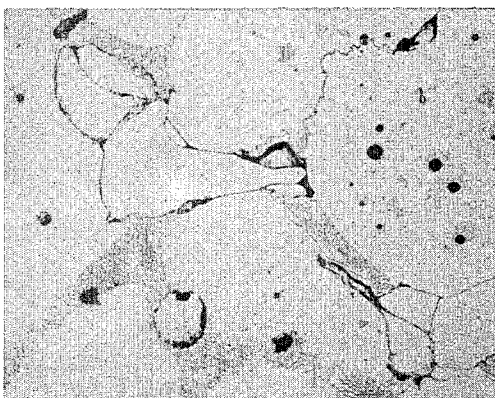


FIG. 2

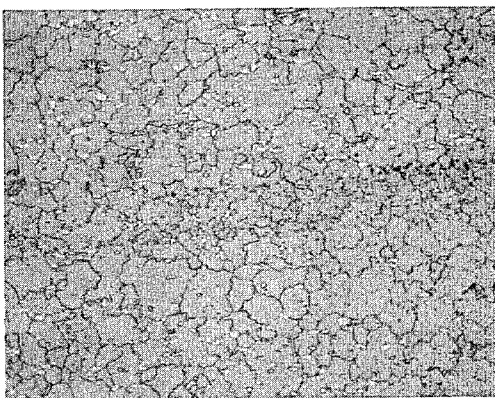


FIG. 1

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METHOD OF FORMING SUPERALLOYS

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11 Claims 10

ABSTRACT OF THE DISCLOSURE

A highly alloyed material obtained using prealloyed powders is easily shaped at high temperatures if it becomes superplastic because of its particular microstructure. Subsequent heat treatments restore the ability of the material to resist deformation at high temperatures.

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention is concerned with shaping high strength superalloys. The invention is particularly directed to the use of powder metallurgy to produce an ultrafine grain size which results in superplastic behavior at high temperatures.

Conventionally cast and wrought alloys are utilized for the hot components of gas-turbine engines. Cast nickel-base alloys are generally used for turbine buckets and stator vanes, whereas wrought alloys are used for turbine discs. In more advanced engines wrought nickel-base alloys are also used for compressor discs and blades in the latter compressor stages.

The operating cycle temperatures must be raised in advanced engines to meet the demand for increased performance. Nickel-base alloys that can be used at high temperatures throughout the engine have been suggested. However, most high strength nickel-base alloys are highly alloyed and metallurgically very complex. As a consequence, severe macro- and micro-segregation can occur in castings, such as turbine buckets and stator vanes, so that the full-strength potential of the alloy is not realized. Also, in ingots, the usual starting stock for breakdown operations, segregation increases the difficulty of forming the alloys.

SUMMARY OF THE INVENTION

Fine prealloyed powders of highly alloyed superalloy compositions may be consolidated and then shaped in separate steps. Likewise these powders may be consolidated and shaped simultaneously. During the shaping operation the consolidated powders are heated to temperatures at which the material exhibits superplastic behavior, and only relatively low pressures need be applied to shape the material.

At intermediate temperatures significant increases in strength over the cast or wrought counterparts of the alloyed material can be obtained by alloys consolidated or shaped in accordance with the invention. Suitable heat treatments can also improve elevated temperature properties compared to the cast or wrought counterparts of the alloys. For example, heat treating at temperatures between the solidus and liquidus with a simultaneous imposition

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of isostatic pressure is used to obtain a suitably coarse microstructure and a solidification structure resulting from partial melting at the grain boundaries that will provide good high temperature strength and a structure free from voids.

OBJECTS OF THE INVENTION

It is, therefore, an object of the present invention to produce articles of manufacture from superalloy compositions which are too highly alloyed to be cast without gross segregation.

A further object of the invention is to provide a method of making a superalloy article of manufacture in which significant deformation is achieved with relatively low applied forces using a minimum number of steps.

A still further object of the invention is to provide a method of making a superalloy article of manufacture in which the microstructure of the formed material is coarsened by heat treating at temperatures above the incipient melting point of the alloy without void formation.

Another object of the invention is to provide superalloys having higher strength at intermediate or at high temperatures than can be obtained by conventional cast and cast-wrought processes.

These and other objects of the invention will be apparent from the specification which follows and from the drawing.

DESCRIPTION OF THE DRAWING

The figures are micrographs of HS-31 powder product at a magnification of 500.

FIG. 1 shows the as-extruded alloy,

FIG. 2 shows the material after the first step of heat treatment, and

FIG. 3 shows the material after final heat treatment with the application of pressure.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The method of the present invention utilizes prealloyed powders of a highly alloyed superalloy composition. The powders are extremely fine and have a high purity.

The powders can be prepared by inert gas atomization or other methods, such as the rotating electrode method. To produce the powders by atomization remelt stock is first melted under an inert gas or in vacuum in an induction furnace, and the melt is then atomized under an inert gas. The resulting powders are screened, and only suitable size powders are used for further processing in accordance with the invention.

The prealloyed powders are then consolidated in the form of either bar stock or preforms. More particularly, the prealloyed powders can be made into bar stock by extrusion, or by a combination of hot pressing and extrusion. These powders can also be made into preforms for turbine buckets or other desired articles of manufacture. These preforms are made by slip-casting, by pressing in a shaped die, or by enclosing the powder in a suitably shaped container, such as a metallic can.

An important feature of the invention is that the consolidated powders are heated to a temperature at which the material exhibits superplastic behavior. While a blank or preformed shape of these consolidated powders is still hot, pressure is applied to form the powders into the desired configuration. This pressure may be applied unidirectionally to suitably shaped dies.

Because of the superplastic behavior of the material a very low pressure is required to shape the consolidated powders. The shaping may be accomplished at pressures as low as 1000 p.s.i.

The formed part or article of manufacture may then be heat treated to obtain suitably coarse microstructures for superior high temperature strength. If an isostatic pressure is simultaneously imposed the heat treating temperature may be above the incipient melting point or solidus of the powder material.

EXAMPLES

In order to better illustrate the invention test samples of an experimental nickel-base superalloy were prepared and tested. The nominal composition of the alloy is shown in Table I.

TABLE I.—NOMINAL COMPOSITION OF ALLOY

Element:	Wt. percent
Tantalum -----	8
Tungsten -----	4
Molybdenum -----	4
Columbium -----	2.5
Chromium -----	6
Aluminum -----	6
Zirconium -----	.75
Carbon -----	.125
Nickel -----	Balance

Vacuum remelt stock of the nickel-base superalloy was melted under argon in an induction furnace. The melt was atomized under argon to spheroidal powders which were screened with Tyler screens to -60 mesh. Only the -60 mesh fraction was used for further processing. The sieve analyses for the -60 mesh fraction for the alloy is shown in Table II.

TABLE II.—PARTICLE SIZE DISTRIBUTION OF ATOMIZED POWDER

Tyler screen size:	Percent
60/100 -----	5.0
100/500 -----	13.5
150/270 -----	30.0
270/325 -----	7.0
325/400 -----	9.0
<400 -----	35.5

These fine powders were sealed in evacuated mild steel cans. The canned powders were heated to 2200° F. in a furnace and transferred to an extrusion press. Here the powders were extruded into bars and the cans were reduced in size from 2 inches to approximately 5/16 inch in diameter by passing them through an extrusion die.

The bars were first tested in the as-extruded condition. The nickel-base alloy had an elongation of more than 600% after testing at 1900° F. and 1000 p.s.i. for 4.1 hours. These very high elongations which occurred in elevated temperature tensile and stress rupture tests indicated superplastic behavior.

Samples of the as-extruded powder product of the alloy were upset to show that the material can be formed in compression to take advantage of this superplastic behavior. A hydraulically operated press with an in-place graphite susceptor induction heating furnace was used. Bar specimens approximately 5/8 inch high were heated to 2000° F. and pressed. Pressure was applied to the circular ends of the specimens through high temperature alloy plates which were heated to the same temperature as the specimen. An initial load of 155 pounds was applied. The load was increased as necessary to maintain a relatively constant strain rate of between 0.03 to 0.07 inch per inch per minute. This strain rate was used to approximate the rate observed when superplasticity was encountered with the alloy in a stress rupture test. The specimen had a diameter of 1.1 inch and a thickness of 0.175 inch after pressing.

Heat treatments to effect solutioning and aging were performed in vacuum or under argon on unmachined extruded bars of the nickel-base alloy. These heat treatments coarsened the microstructure of extruded powder

products and substantially improved stress rupture life for the alloy compared to the life of the as-extruded powder product at an intermediate temperature. At 1200° F. and 105,000 p.s.i. the extruded and heat-treated powder product of the alloy had a rupture life of 975 hours, whereas the as-extruded powder product had a life of 374 hours.

Heat-treated extruded samples of the alloy had substantially lower rupture life at high temperatures of 1800 to 2000° F. than as-cast samples. For the heat treated, extruded powder product it was 2.2 against 90 hours at 1900° F. and 15,000 p.s.i.

By simultaneously applying pressure and heat the incipient melting point of the as-extruded nickel-base alloy powder product was exceeded without void formation. It was successfully heated to 2400° F. which is about 50° above the incipient melting point under a pressure of 10,000 p.s.i. By simultaneous application of pressure and the high temperature the microstructure was coarsened to a greater degree than by conventional heat treatments.

Test samples of a commercial cobalt-base alloy were also prepared and tested to illustrate the beneficial effect of the heat treatment that utilized both high temperatures above the incipient melting point and high pressures. The cobalt-base alloy identified as HS-31 was made by the aforementioned prealloyed powder process. The microstructure of as-extruded HS-31 powder product is shown in FIG. 1.

As-extruded bars of the cobalt-base alloy were heat treated for 1 hour at 2400° F. at atmospheric pressure. The microstructure after this heat treatment is shown in FIG. 2. This is about 60° F. above the incipient melting point.

The grain growth was accompanied by the formation of large voids. Subsequent application of isostatic pressure of 30,000 p.s.i. at 2200° F. grew the grains further and closed the voids. This restored the integrity of the sample as shown in FIG. 3. Operation at 13,000 p.s.i. and 1800° F. resulted in a 20 hour life, which is double that of the as-cast alloy. Operations at 61,000 p.s.i. and 1200° F. resulted in a 420 hour life compared to 10 hours for the cast alloy.

What is claimed is:

1. A method of making a formed powder product comprising the steps of:
forming prealloyed powders of a highly alloyed composition,
consolidating said prealloyed powders into a predetermined configuration,
heating the consolidated prealloyed powders to a first temperature at which the consolidated powders exhibit superplastic behavior, said first temperature being substantially below the solidus temperature,
shaping the consolidated powders at said first temperature by applying a low stress whereby a controlled low strain rate is achieved,
heat treating the formed powder product by heating the same to a second temperature that is between a solidus and liquidus, and
imposing isostatic pressure on the formed powder product to close any voids therein.
2. A method of making a formed powder product as claimed in claim 1 wherein the isostatic pressure is imposed simultaneously with heating the formed powder product to the second temperature between the solidus and liquidus.
3. A method of making a superalloy article of manufacture comprising:
forming prealloyed powders of a highly alloyed superalloy composition,
consolidating said prealloyed powders into a predetermined configuration,
heating the consolidated prealloyed powders to a temperature at which the consolidated powders exhibit

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- superplastic behavior, said temperature being substantially below the solidus temperature, shaping the heated consolidated powders by applying a low stress whereby a controlled low strain rate is achieved, heat treating the shaped superalloy article of manufacture by heating the same to an elevated temperature between the solidus and liquidus, and imposing isostatic pressure at said elevated temperature to close any voids in the material.
4. A method as claimed in claim 1 wherein the prealloyed powders are a nickel-base alloy.
5. A method as claimed in claim 1 wherein the prealloyed powders are a cobalt-base alloy.
6. A method as claimed in claim 1 wherein the prealloyed powders are consolidated by extruding the prealloyed powders into bar stock.
7. A method as claimed in claim 1 wherein the prealloyed powders are consolidated into a preform.
8. A method as claimed in claim 7 wherein the preform is shaped by applying a substantially constant low pressure to the preform.
9. A method as claimed in claim 8 wherein the low pressure is applied within a die.

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10. A method as claimed in claim 1 wherein the prealloyed powders are consolidated while enclosed in a shaped container.
11. A method as claimed in claim 10 including the step of enclosing the powder in a metallic can.

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