

Nov. 8, 1966

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3,283,377

TURBINE WHEEL MANUFACTURING METHOD

Filed June 29, 1964

3 Sheets-Sheet 1

Fig-1

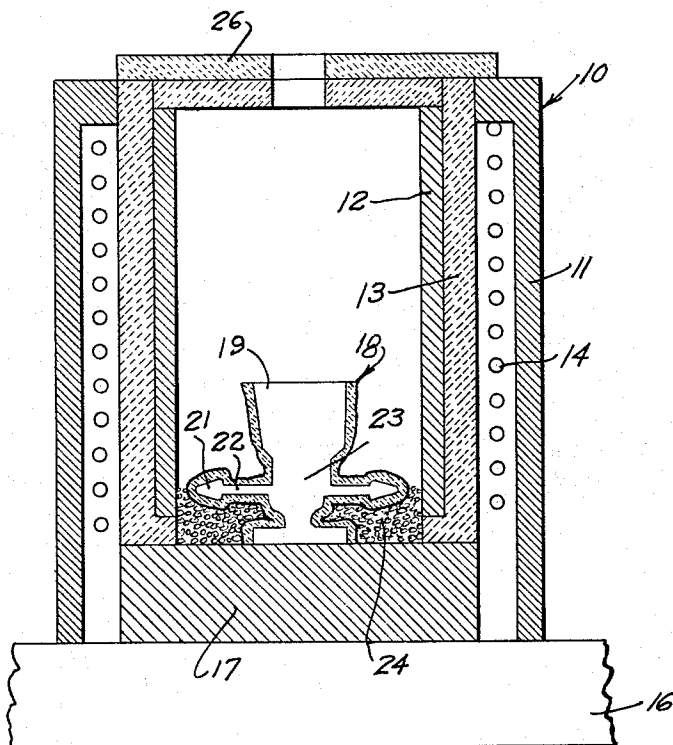
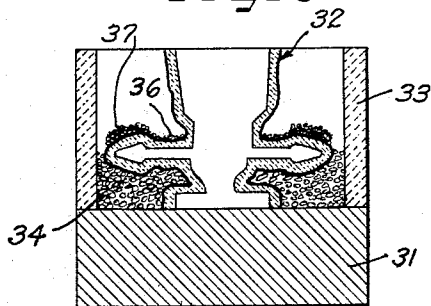


Fig-6



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Fig-2

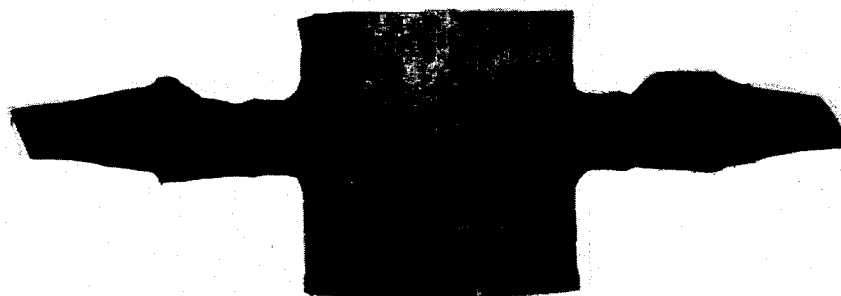
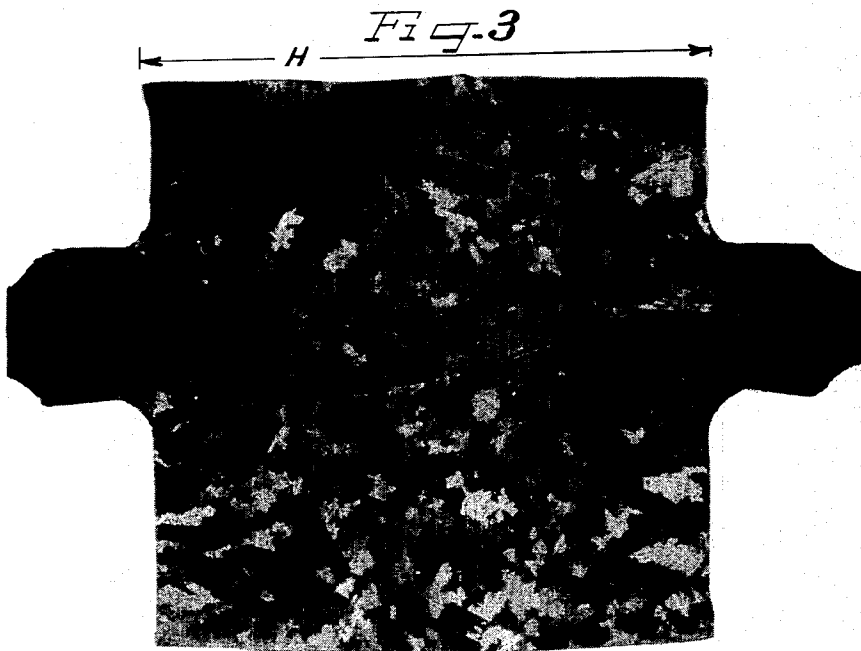


Fig-3



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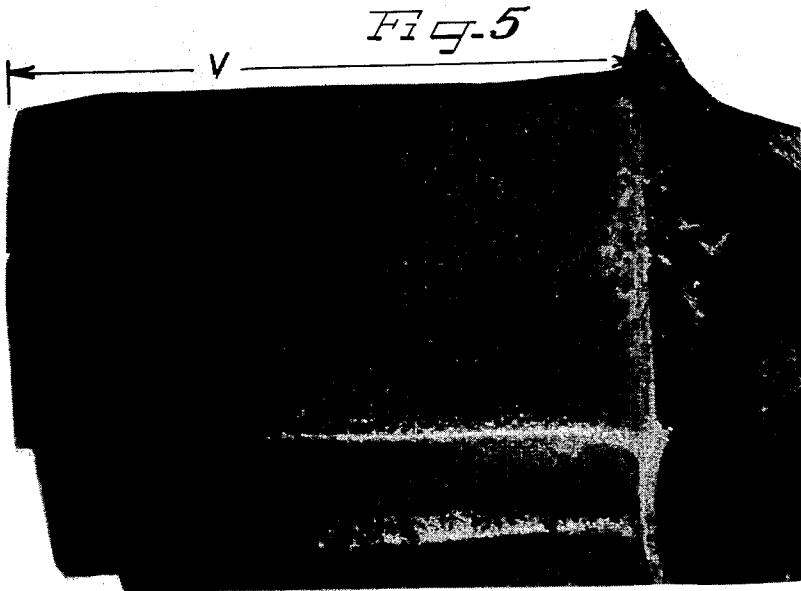
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Fig-4



Fig-5



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TURBINE WHEEL MANUFACTURING METHOD

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4 Claims. (Cl. 22-212)

The present invention is directed to an improved turbine wheel for jet engines and also embodies improvements in methods and apparatus for the manufacture of an improved turbine wheel.

One of the limiting factors in the design of any turbine engine has been the ability of the turbine wheel to withstand the conditions of temperature and stress existing during operation of the engine. Turbine wheels in particular must be capable of withstanding dynamic loads under high stress conditions and have satisfactory creep characteristics at elevated temperatures. Substantial advances have been made in the chemistry of alloys used for turbine wheels, with the result that permissible turbine inlet temperatures have increased, thereby markedly increasing the net output and the cycle efficiency of the engine.

Control of the chemistry of the alloy, however, is not alone sufficient to provide an optimum solution to the problem. Different portions of the turbine wheel are subjected to different kinds of stresses, in different amounts. The present invention provides a structure which has the proper grain characteristics in various portions of the wheel which are best suited to resist the particular stresses which that portion of the structure is to encounter during use.

It would be highly desirable if a turbine wheel could be manufactured as a cast integral structure. However, existing technology for the production of cast turbine wheels is deficient in that it has not been possible to cast equiaxed grain size in the thin air foil sections of the wheel and, at the same time, produce sound, equiaxed grain size in the heavier, hub section of the wheel. The present invention overcomes this problem, and provides a cast turbine wheel having thick and thin sections of equiaxed, sound structure having greatly improved ductility properties.

An object of the present invention is to provide an improved cast, integral turbine wheel structure in which the grain configuration is substantially identical throughout the casting but the grain sizes vary at different portions thereof.

Another object of the invention is to provide a cast, integral turbine wheel which has substantially improved ductility properties.

Still another object of the invention is to provide a method for casting a turbine wheel or the like through the use of differential temperature gradients which are so arranged as to provide the desired grain structure and grain sizes in the finished article.

Still another object of the invention is to provide a method for producing a casting of exceptional soundness and ductility from high temperature alloys.

A further object of the invention is to provide an improved apparatus for the casting of alloys in the formation of turbine wheels and the like.

The turbine wheel of the present invention has a geometry which is standard, in that it contains a relatively massive hub section, a wheel portion extending annularly about the hub section, and vanes extending radially outwardly from the wheel portion. The difference in structure (and the resultant improvement in physical properties) is attributable to the orientation of the grain in the integral casting. Specifically, the grain size in the hub section is made relatively large, the grain in the vanes is relatively fine, and the grain size in the wheel portion

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is intermediate that of the vanes and the hub portions. In all sections, the grain configuration is substantially equiaxed.

The method involved in making the improved turbine wheel consists in positioning a ceramic shell mold or the like on a heat abstracting surface in a furnace enclosure, the mold having communicating molding cavities defining a hub section, a wheel portion extending around said hub section, and vanes extending radially outwardly from the wheel portion. The mold is preheated by means of radiant energy until the walls of the cavities which define the thin wall sections of the casting, i.e., the walls defining the vane forming cavities, reach a temperature approximating that of the pouring temperature of the metal alloy. Concurrently, a substantial portion of the cavity defining the relatively massive hub is shielded from the radiation to provide a substantial temperature differential between the mold in the area of the vanes and in the area of the hub. Then, a molten alloy at a temperature not more than about 200° F. above its liquidus temperature is cast into the mold. The hub defining cavity is in open communication with the heat abstracting surface so that the casting is rapidly solidified in the hub defining portion of the mold. The low pouring temperature permitted by this procedure produces a fine equiaxed grain size in the vanes, and the thermal gradients established by the heat abstracting surface produce a casting of exceptional soundness and ductility.

A further description of the present invention will remain in conjunction with the attached sheets of drawings, in which:

FIGURE 1 is a cross-sectional view of a mold assembly which can be employed for the purposes of the present invention;

FIGURE 2 is a photographic reproduction of a turbine wheel produced according to the present invention, cut away and etched to illustrate the grain configuration;

FIGURE 3 is an enlarged reproduction of the hub portion of the turbine wheel shown in FIGURE 2;

FIGURE 4 is an enlarged reproduction of the wheel portion of the structure shown in FIGURE 2;

FIGURE 5 is an enlarged reproduction of the vanes of the turbine wheel; and

FIGURE 6 is a cross-sectional view illustrating another form of the invention.

As shown on the drawings:

In FIGURE 1, reference numeral 10 indicates generally a furnace assembly of the type which may be employed in accordance with the present invention. The furnace assembly 10 includes outer walls 11 composed of a suitable refractory brick material or the like, and an inner radiating enclosure, such as a graphite susceptor 12. Between the outer walls 11 and the susceptor 12 is a layer 13 of an insulating refractory material. The susceptor 12 is heated to the high temperatures involved by means of an induction coil 14 disposed between the insulating material 13 and the outer walls 11.

The outer walls 11 rest upon a support 16, and on this support there is a heat abstracting surface provided by a block 17 composed of a highly heat conductive material such as copper. Additional heat transfer means, such as a water circulating system can be embodied within the block 17.

A ceramic shell mold 18 of generally uniform wall thickness rests on the block 17. The mold 18 generally has a thickness from about 1/16 inch to about 1/4 inch or so. It includes an open-ended riser cavity portion 19 which delivers the molten metal to a plurality of communicating molding cavities, including cavities 21 which define the vane portions of the turbine wheel casting, a continuous cavity 22 which defines the wheel portions

of the finished casting, and a centrally disposed cavity 23 which defines a relatively massive hub of the finished article. As seen in FIGURE 1, the hub defining cavity 23 is in open communication with the heat conductive block 17 so that heat may be immediately abstracted from the cavity 23 upon pouring of molten metal therein.

While there are a number of ways in which to produce the shell molds useful for the purposes of the present invention, I particularly prefer to use the method described in Mellen et al. U.S. Patent No. 2,932,864, issued April 19, 1960. In the method described in that patent, a destructible pattern of the article to be reproduced is coated at room temperature by dipping it in an aqueous slurry containing refractory particles and a binder. This coating is then dried adiabatically so that the temperature of the pattern remains constant. The drying is achieved by passing air of controlled humidity past the coated pattern, the air containing sufficient moisture to maintain a substantially constant wet bulb temperature which is substantially the same as the initial temperature of the pattern and having a dry bulb temperature which is at least 10 F. higher than the wet bulb temperature. The pattern is then dipped in additional aqueous refractory slurries to form successive layers on the pattern. Each successive layer is adiabatically dried in the same manner as described previously while maintaining the temperature of the pattern substantially constant. Finally, the pattern is removed by melting it out, and the resulting multi-layer mold is fired at temperatures on the order of 1500 to 1900° F. to produce a porous, hard, smooth surfaced shell mold.

In order to provide temperature differentials within the mold itself, a portion of the outer walls of the mold is embedded in a radiation shielding material such as particulate magnesia 24 or other refractory material. The function of the bed 24 is to shield the bottom of the mold from the radiation source and thereby provide a substantially lower temperature in the vicinity of the casting cavity 23 than in the vane defining cavities 21.

Initially, the susceptor 12 is brought to a high temperature such as 2300 to 2500° F. and this temperature is maintained until the portions of the mold which define the thinner sections, such as the walls of the vane defining cavities 21 are brought up to about that temperature. The alloy to be cast is melted and held at a temperature not exceeding about 200° F. above its liquidus, and usually around 75° F. above the liquidus temperature. The molten metal is then poured into the mold through a heat shield 26 which prevents heat loss from the top of the mold. The entire casting operation is preferably carried out under vacuum conditions to avoid oxidation of the metal.

After pouring, the metal is allowed to cool in the mold until it is solidified. The mold is then broken away and the finished article is recovered. The low pouring temperature produces a fine equiaxed grain size in the casting, and the thermal gradients established by the heat conductive block 17 produce a casting of exceptional soundness and ductility.

The process of the present invention is applicable to any type of metal or alloy, but finds particular utility in the casting in the so-called "superalloys" which are essentially nickel-chromium base alloys. A typical range of composition for such alloys is given in the following table:

TABLE I

	Percent
Carbon	.05 to 0.20
Chromium	8 to 15
Tungsten	3 to 10
Cobalt	8 to 12
Titanium	0.5 to 2
Aluminum	4 to 8
Columbium	up to 3
Boron	up to 0.05

TABLE I—Continued

Zirconium	up to 0.20
Nickel	Substantially the balance

The grain structure of the resulting castings is shown by means of photographic reproductions in FIGURES 2 to 5 inclusive. In FIGURE 2, the relatively massive hub section has been identified at reference character H, the intermediate wheel section by the reference character W, and the vanes by means of reference character V. These sections are individually shown in the enlargements constituting FIGURES 3 to 5 of the drawings.

From an inspection of FIGURE 3, it will be seen that the grain structure of the hub section H is equiaxed and is otherwise completely sound. The average grain size in the hub section is usually in the range from about 1/4 to 1/2 inch. Not only is the structure metallurgically sound, but the physical properties of the hub section are substantially improved over castings from the same alloy made in the conventional manner. For example, the hub section evidences a tensile strength in excess of about 120,000 p.s.i., an elongation of at least 8%, and a reduction in area of at least 8%, all measured at room temperature. Specifically, the following table lists the improvements in physical properties which are obtained from castings produced according to the present invention, and those observed in the same alloy cast by conventional casting techniques:

TABLE II

Heat No.	Tensile strength, p.s.i.	Percent Elongation	Percent Red. in Area
1.....	151,000	14.0	12.5
2.....	132,000	10.0	13.0
Conventional.....	120,000	1.5	3.0

The intermediate wheel portion, as shown in the enlargement of FIGURE 4, has an average grain size which is generally smaller than that appearing in the massive hub portion H. Generally, the wheel portion has a grain size ranging from about 1/8 to 1/4 inch. The photograph of FIGURE 4 is taken in deeply etched section, and illustrates a complete lack of microporosity in the cast articles.

The vanes, V, as illustrated in FIGURE 5, are a fine, uniformly equiaxed grain structure. The average grain size is on the order of about 1/64 of an inch.

The casting from which the photographs of FIGURES 2 to 5 were taken was an integral turbine wheel of about 12" diameter containing 36 vanes. A ceramic shell mold was employed, and the heat source was a graphite susceptor disposed within an induction coil. Granular magnesia of about 3/16" diameter was used to shield the heat abstracting surface and the bottom of the hub portion of the mold. The susceptor was heated to 2400° F. for 14 minutes under a vacuum of about 60 microns, and the mold was filled with a low carbon, nickel-chromium alloy (INCO 713-C) at a temperature of about 2500° F.

A modified form of the invention is illustrated in FIGURE 6 of the drawings. In this embodiment, there is provided a block 31 of a material such as copper having high thermal conductivity. Resting on the block 31 is a ceramic shell mold 32 which may be identical to the shell mold 18 previously described. A refractory cylinder 33 surrounds the periphery of the mold 32 and is positioned on the block 31. A bed 34 of refractory particles is also provided about the lower extremities of the mold 32.

Instead of preheating the mold in an induction furnace, as illustrated in FIGURE 1, the assembly of FIGURE 6 employs an exothermic material such as "Thermit," a mixture of iron oxide and finely divided aluminum as the source of heat. A relatively thin layer 36 of the exothermic material may be placed over the portions of

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the cavity defining the wheel portion of the casting, and a relatively thicker layer 37 may be placed adjacent the vane defining portions. Ignition of this exothermic material prior to pouring of the metal thus provides heat to the thin walled portions of the mold cavity while allowing the thicker portions of the mold cavity and heat abstracting surfaces to remain relatively cooler.

From the foregoing, it will be understood that the turbine wheel of the present invention consists of an integral casting in which the grain size varies within the various portions of the wheels. In all cases, the structure is substantially equiaxed, providing the required soundness and freedom from porosity. The substantial improvement in physical properties of the wheels establish a significant improvement over similar articles of the past.

It should be evident that various modifications can be made to the described embodiments without departing from the scope of the present invention. For example, the process and apparatus can be applied to the manufacture of gears and the like, since only changes in the geometry of the mold are required, the teeth of the gear corresponding to the vanes of a turbine wheel.

I claim as my invention:

1. The method of making a turbine wheel which comprises positioning a ceramic shell mold on a heat abstracting surface in a furnace enclosure, said mold having communicating molding cavities defining a hub section, a wheel portion extending annularly about said hub section, and vanes extending radially outwardly from said wheel portion, radiating thermal energy at said mold, shielding a substantial portion of the cavity defining said hub section from the radiation, continuing the heating until the portions of the mold in which the thickness

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dimensions of the cavities is the smallest achieve temperatures on the order of the pouring temperature of the alloy to be cast, casting a molten alloy into said mold at a temperature not more than 200° F. above its liquidus temperature, and cooling the resulting casting in said mold to produce a cast turbine wheel having a hub section with a relatively large grain size, vanes with a relatively fine grain size, and a wheel portion with a grain size intermediate that of said hub section and said vanes.

2. The method of claim 1 in which said shielding is accomplished by disposing a granular refractory material about said portion of the hub-defining cavity.

3. The method of claim 1 which said alloy is a nickel-chromium alloy, and said alloy is poured at a temperature of about 2500° F.

4. The method of claim 1 in which said casting is done under vacuum conditions.

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