

June 5, 1956

C. G. GOETZEL ET AL

2,749,029

COMPRESSOR BLADE

Filed Nov. 26, 1948

2 Sheets-Sheet 1

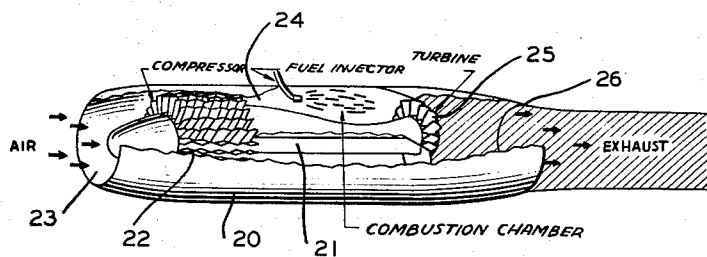


Fig. 1

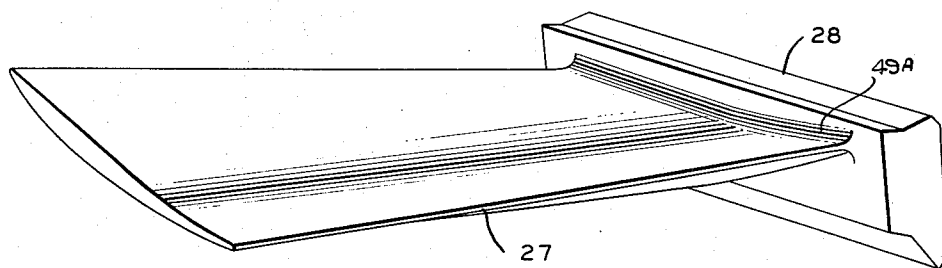


Fig. 2

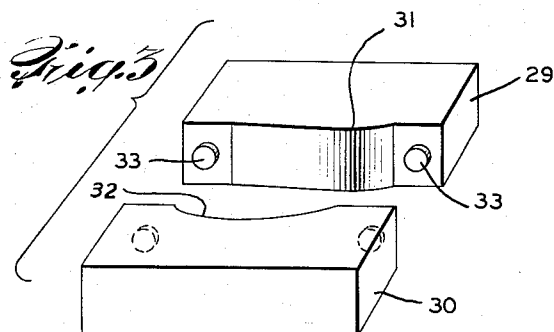


Fig. 3

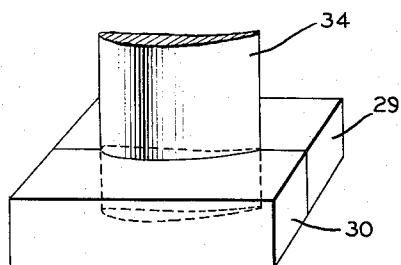


Fig. 4

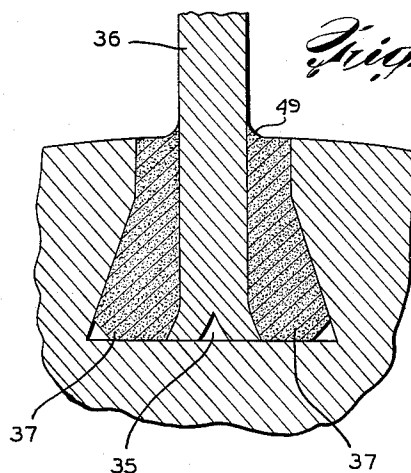


Fig. 5

INVENTORS
CLAUS G. GOETZEL
BY JOHN L. ELLIS

ATTORNEYS

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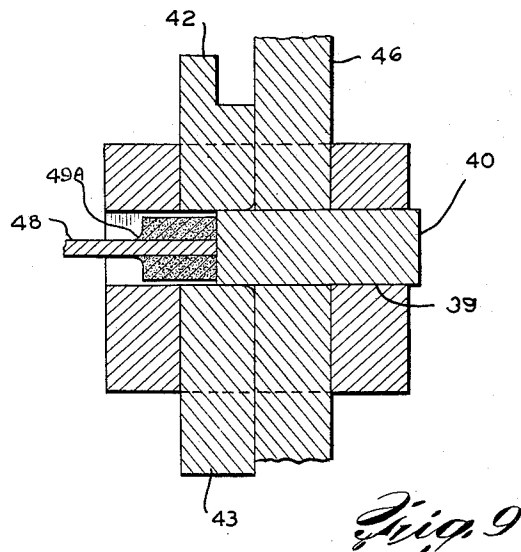
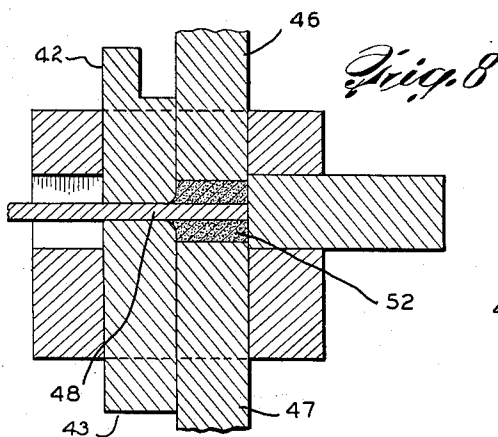
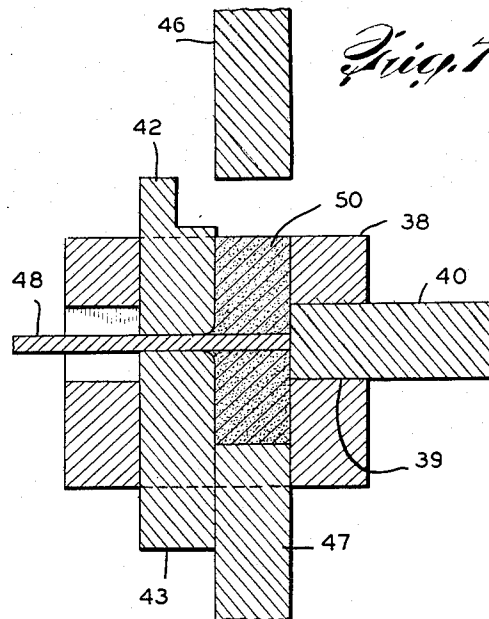
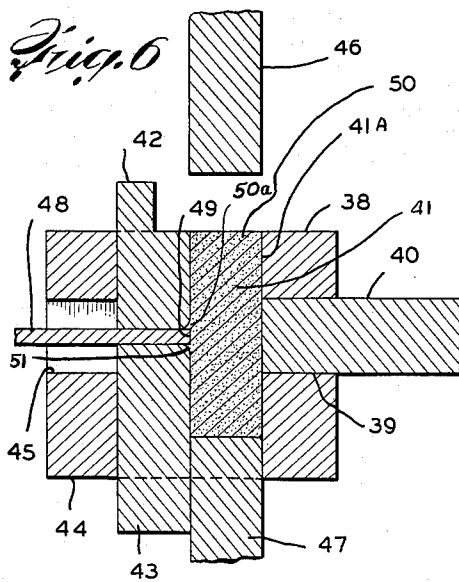
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2 Sheets-Sheet 2



INVENTORS
CLAUS G. GOETZEL
BY JOHN L. ELLIS
Hammond & Littell
ATTORNEYS

1

2,749,029

COMPRESSOR BLADE

Claus G. Goetzel, Yonkers, and John L. Ellis, New York, N. Y., assignors to Sintercast Corporation of America, New York, N. Y., a corporation of New York

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7 Claims. (Cl. 230-134)

This invention relates to a compressor blade and especially a blade suitable for use in a jet or gas turbine engine compressor or the like, wherein the blade is subjected to relatively high forces.

In a conventional jet engine, there is a rotating shaft having a plurality of rows of air compressor blades at its front end, the compressor being followed by a combustion chamber. Turbine blades mounted on said shaft follow the combustion chamber, said turbine blades being acted upon by the high temperature burning gases. The compressor blades normally operate at moderate temperatures (300°-800° F.), forcing the air which is fed into the front end of the jet engine into the combustion chamber. The clearances between blade elements in the compressor blade section of the engine are considerably more critical than the clearances in the turbine blade section. The compressor blades are subjected to extremely high stresses because of the high speed of operation of the turbine shaft in a jet engine, said speeds being as high as 18,000 revolutions per minute. A compressor blade of the type contemplated herein normally has an airfoil and a foot section. The foot section is shaped to be engageable with a groove or suitable holding means on the turbine shaft. Because of the enlarged portion, conventional rolling and extruding processes cannot be used to form the complete blade. The physical characteristics of materials having the desired strength and the complex shape and twist in the airfoil section also make conventional cutting and machining operations difficult to perform.

One of the objects of the invention is to produce a compressor blade having the desired characteristics which can be manufactured in an economical and facile manner utilizing wrought airfoil sections.

One of the features of the invention is the use of a preformed wrought steel airfoil section with a separately formed porous metal impregnated foot section intimately bonded thereto. The airfoil section can be rolled or extruded, for example, and then cut off to the proper length. The foil preferably is made of a metal having an alloying constituent, which is the same as an alloying constituent of the infiltrant metal used to impregnate the foot section skeleton body. This foot section is formed from a porous metal powder skeleton body placed in contact with one end of the airfoil section and impregnated with an infiltrant metal. The skeleton body, the infiltrant metal and the airfoil section preferably have the same alloying constituent. As known from powder metallurgical impregnation techniques, a porous skeleton body can be formed and then impregnated or infiltrated with a second lower melting metal or metal alloy.

By performing the infiltration while the foot section is in contact with the airfoil section, an intimate bond is produced by an interaction between the alloying elements of the airfoil section on the one side, and the foot section and its infiltrant metal on the other side. It can be well assumed, that there is an atomic interchange of the alloy-

2

ing constituent of the airfoil section and the alloying constituent of the infiltrant metal. Also, there is an atomic interchange of the alloying constituent of the foot forming skeleton material and the alloying constituent of the infiltrant metal.

In a preferred form of the invention, the alloying constituent involved is chromium and the air foil section may be made from an extruded or rolled chromium containing stainless steel alloy. The foot section consisting of a metal infiltrated skeleton body which may be formed from various metal powders having chromium as the alloying constituent, the metal powder being preferably of the same composition as the air foil section. The infiltrant preferably has chromium as the minor alloying constituent thereof, the major alloying constituent being preferably copper. Other alloying constituents which can be used in place of the chromium for atomic interchange purposes are silicon, aluminum and nickel.

The skeleton constituting the foot section may be formed on the airfoil section in situ or separately and then placed in contact therewith, the important feature being that the infiltration of the foot section by the auxiliary metal takes place while the skeleton constituting the foot section is mounted in its proper place relative to the airfoil section. The foot section preferably should have the same composition as the airfoil section so that the coefficients of expansion will be the same.

The infiltrant alloy has preferably copper as the major constituent and chromium as the minor alloying constituent. By the use of this infiltrant, the bond between the foot and airfoil section and the physical characteristics, particularly strength, are improved because of the precipitation hardening of the copper chromium infiltrant alloy. Other suitable precipitation hardenable infiltrant alloys may be used such as copper-nickel-tin, copper-silicon, and copper-aluminum, depending upon the minor constituent used for the air foil section.

In another aspect of the invention, the joining of the two sections can be further improved by a mechanical keying of the airfoil with the foot section by a splitting or upsetting of the end of the foil section where it protrudes or is at the end of the foot section.

In addition to using a stainless steel wrought airfoil section, a carbon steel airfoil section may be used and its surface may be coated by chromizing, silicizing, aluminizing, depending upon the metal taking part in the atomic interchange. The skeleton body constituting the porous foot section can be put in place on the airfoil section if chromium is employed as an alloying constituent, it is preferable to use a gas chromizing process. If the foot is molded in place and a chromizing treatment used, the assembly should be rechromized before infiltration.

For salt water spray resistance, an austenitic and therefore nickel containing stainless steel may be used for the airfoil section and a copper-nickel-tin infiltrant alloy wherein nickel may be the atomic interchange element.

Another of the objects of the invention is to form a powdered metal skeleton on a wrought foil section in an improved manner.

This can be accomplished by pressing and forming the powdered metal in place on the airfoil section in such a manner that there is substantially no movement of the particles of the metal along the surface of the airfoil as pressure is exerted on the loose particles.

One of the advantages of the invention is that the airfoil section can be accurately and economically produced by various conventional shaping methods, and its shape retained during the further processing and operation of placing the foot section thereon. The airfoil section can be cut and trimmed from extruded or rolled

steel shapes, twisted and straightened and then the formed metal powder foot section infiltrated when placed on the airfoil section.

The formed blade can be subjected to such heat treating as is deemed desirable.

These and other features, advantages, and objects of the invention will become apparent from the following description and drawings which are merely exemplary.

In the drawings:

Figure 1 is a schematic view of one type of jet engine with which the invention may be used.

Figure 2 is a perspective view of one form of blade.

Figure 3 is a perspective view of one form of foot section.

Figure 4 shows the form of Figure 3 in place on the end of a blade.

Figure 5 shows a modified form of the invention after installation in the compressor disc.

Figure 6 shows one manner in which the powdered metal foot section can be formed wherein the powdered metal is placed in an aperture in a molding machine.

Figure 7 shows the next step in the operation of the machine of Figure 6.

Figure 8 shows the compression of the powdered metal on either side of the blade section.

Figure 9 shows the ejection of the powdered metal formed foot section prior to infiltration.

The jet engine seen in Figure 1 is merely exemplary of one use of the compressor blade of the present invention. Casing 20 may have a shaft 21 supported on suitable bearings (not shown) rotatable within said casing, said casing having compressor blades 22 for receiving air through opening 23 and forcing the same rearwardly to combustion chamber 24. Turbine blades 25 are subjected to the heated gases in the combustion chamber, said gases exhausting through the exhaust end 26 of the engine and performing work as they pass the turbine blades. The compressor blades 22 are very critical in their clearances and must have high strength characteristics because of the high rotating speeds of the engine shaft. There are both rotor and stator blades involved.

One form of blade is seen in Figure 2 which can be made in accordance with the present invention, said blade having an airfoil section 27 with a foot section 28 intimately bonded thereto. The foot section 28 is engageable in suitable grooves or holding elements on the shaft as is well known in the art. The airfoil section 27 is formed by extrusion, rolling, or other suitable preforming or shaping processes. The shaped material may be cut off in suitable lengths. The proper twist preferably is placed in the blade as the final operation so as to insure that it is correct. Of course, the twist can be placed therein before the final forming and infiltration of the foot section if desired. By the term "wrought" is meant the aforementioned processes or similar processes wherein the metal is given a desired external cross sectional shape either while hot or cold. The airfoil section preferably may be made of a stainless steel alloy of an austenitic or non-austenitic type. As an example of austenitic stainless steels, one having 18% chromium and 8% nickel or 25% chromium and 20% nickel may be used. An example of a non-austenitic stainless steel is one having 13% chromium. As will be explained hereafter, a carbon steel may also be used.

The foot section is made from powdered metal having the same alloying constituent as the airfoil section, for example, 13% chromium in the case of a non-austenitic steel, and 18% chromium and 8% nickel, or 25% chromium and 20% nickel in the case of an austenitic steel.

An infiltrant alloy used to fill the pores of the porous skeleton may have copper as a major constituent and between 0.1 to 5% chromium as a minor constituent, but preferably in the range .2 to .6% chromium. Cop-

per-silicon also can be used with .1 to 5% of silicon but preferably in the range 2.0 to 4.5% silicon. In the case of a copper-aluminum alloy, the aluminum should be between about .1 and 10% aluminum. The minor constituent of the infiltrant should be selected to agree with the alloying constituent in the airfoil and foot section.

One manner in which the foot section can be formed is seen in Figure 3 wherein the porous metal skeleton is shaped and sintered separately. The foot portions 29 and 30, are provided with shaped portions 31 and 32 designed to closely engage the foil. Projections 33 may be placed on the foot portion for spot welding purposes so as to hold the portions in shape prior to infiltration. Foot portions 29 and 30 are shown in place in Figure 4 at the end of foil 34 ready for the infiltration operation.

Infiltration may be carried out in various manners as described in Powder Metallurgy Bulletin, vol. 1, No. 3, pages 37-42 (1946) by C. G. Goetzel (one of the present applicants) and as described in Product Engineering, vol. 18, No. 8, page 115 (1947) also by C. G. Goetzel. An improvement in the brazing bond between the foot and the airfoil sections is produced by an atomic interchange of the chromium of the airfoil section and the chromium of the infiltrant metal. Also, there may be an interaction between the chromium of the infiltrant metal and the chromium in the skeleton body of the foot portion. It is to be understood that the other atomic interchanging elements such as nickel, silicon and aluminum will produce the same results. As mentioned previously, a further heat treatment may be provided if desired to precipitate chromium-rich or other precipitation hardening constituents.

It also is possible to split the end 35 (Fig. 5) of the airfoil section 36 so that said split section 37 will aid in the anchoring of the airfoil section 36 in the foot section of the blade.

Preferably, the end of the airfoil section to which the foot section is joined has a layer of copper placed thereon. When the powdered metal foot portion is molded directly onto the airfoil section, it is preferable to so mold it that the grains of the powdered metal are not moved lengthwise on the surface of the airfoil section as the foot portion is compressed in relation to the airfoil section, although the foot portion can be formed in other manners.

In Figure 6 is seen an arrangement wherein a powdered metal foot section may be formed on an airfoil section. The die 38 may have an aperture 41A therethrough, reciprocable ejection plunger 40 passing through guide aperture 39 in one wall of the die. A powdered metal cavity 41 is formed in aperture or port 41A. The outwardly movable airfoil section positioners 42, 43, are guided in the port of the die. Aperture 45 in wall 44 serves as an opening through which the airfoil section is inserted and through which the airfoil section with the foot section thereon is ejected.

Upper compression plunger 46 and lower compression plunger 47 are oppositely reciprocable relative to each other and cavity 41, the lower plunger 47 forming the bottom of cavity 41 when the loose powdered metal is placed therein. Airfoil section 48 is placed between positioners 42 and 43; the end 49 of said airfoil section serving to assist in forming cavity 41. Powdered metal 50 is placed in said cavity as seen in Figure 6. A fillet 49A (Fig. 2) may be formed by providing recesses 50A, 51 in positioners 42, 43, respectively. The powdered metal will flow into said recesses and form the desired fillets. It thus is simple to form the necessary fillets on the foot section so as to give the desired strength characteristics at the joiner of the foot with the airfoil section, said fillet having infiltrant metal bonding the same with the foil.

The next operation is to move the foil 48 inwardly so that the inner end thereof abuts the end of ejection plunger 40. If desirable, an indentation (not shown)

may be formed in conjunction with the end of plunger 40 to assist in positioning the airfoil section.

The next step is the compression of the powdered metal (Fig. 8), the upper plunger 46 and lower plunger 47 being moved inwardly relative to each other the correct distance so as to properly form the foot section 52 on the end of the airfoil section 43. The powdered metal is pressed toward the airfoil section and not along the surface thereof.

The apparatus is then ready for the ejection of the blade with the skeleton foot section formed thereon as seen in Figure 9. First, the foil positioners 42 and 43 are moved outwardly and then plunger 40 moved to the left so as to eject the assembled blade. The formed foot section and airfoil section then can be transferred to a sintering point which is followed by the infiltration process.

The powdered metal is shaped into the foot section by oppositely acting compression plungers which move angularly relative to the surface of the airfoil section, preferably at right angles. The ejection takes place at right angles to the powder compression action.

The airfoil section also can be made of a plain carbon steel containing for example, .5 to 1.1% carbon, the preferred range of carbon being .8 to 1%. Such a steel may have .2 to .6% manganese. A manganese steel also can be used in which the ranges of carbon should be between .5 and 1.1%, the manganese between .5 and 1%, and the silicon between 1.5 and 2.5%. A preferred composition is one having .5 to .6% carbon, .7 to .95% manganese, and 1.8 to 2.2% silicon.

The airfoil section preferably is chromized, silicized or aluminized according to the foot and infiltrant alloy, when a plain carbon or manganese steel is employed. The foot section can be formed from alloy or carbon steel powders or powder mixtures corresponding to the foil. Upon sintering of these sections, they can be subjected to a treatment of the internal surfaces of the interconnected pores of the skeleton by chromizing, silicizing, and/or aluminizing according to the atomic interchange elements employed. The proper copper alloy infiltrant is selected according to the surface treatment used. The minor alloying constituent being chromium, silicon, or aluminum, so as to give the improved bonding contemplated herein.

Chromizing of the surfaces of the pores of the skeleton body can be accomplished by a gas chromizing process wherein dry hydrogen is passed through fuming hydrochloric acid and over metallic chromium to form CrCl_2 vapor. The vapor is then passed into contact with the foot section to be chromized where the chromium exchanges its chromium atom for an iron atom forming an alloy with the same characteristic structure as chromized iron.

In the case of blades where an increased salt water spray resistance is desired, an austenitic steel can be used having 25% chromium and 20% nickel, or 18% chromium and 8% nickel. The foot section is made of a similar metal. The infiltrant can be for example, 70% copper, 25% nickel, and 5% tin. The tin makes the infiltrant alloy precipitation hardenable and lowers the melting point of the copper-nickel alloy. The nickel in the example just given is the metal common to the foil, foot, and infiltrant.

By the present invention, an object such as a compressor blade can be produced having the required strength and physical characteristics in an economical and improved manner. The improved bonding is believed to be due to an atomic or molecular interchange, although other factors or mechanisms may be involved. The surface coating of the plain steel can be carried out before or after the foot section is in place, although it is preferred to be done first. The details of construction and materials can be varied without departing from the

spirit of the invention except as defined in the appended claims.

What is claimed:

1. A compressor blade having an airfoil section and a foot section joined and intimately bonded thereto, the airfoil section comprising a preshaped wrought steel member containing an alloying constituent of an atomic interchange bond-promoting element at least adjacent the surface thereof, the foot section comprising a sintered metal skeleton body having interconnecting pores distributed therethrough which contain an infiltrant metal having as an alloying constituent said atomic interchange bond-promoting element, the intimate bond comprising the wrought airfoil section on one side and the sintered skeleton body of the foot section and its contained infiltrant metal on the other side.

2. A compressor blade according to claim 1 wherein the surface of the foot section contains as an alloying constituent an atomic interchange bond-promoting element.

3. A compressor blade having an airfoil section and a foot section joined and intimately bonded thereto, the airfoil section comprising a preshaped wrought steel member containing an alloying constituent of an atomic interchange bond-promoting element selected from the group consisting of chromium, nickel, aluminum and silicon at least adjacent the surface thereof, the foot section comprising a sintered metal skeleton body having interconnecting pores distributed therethrough which contain an infiltrant metal having as an alloying constituent the atomic interchange bond-promoting element as contained in said wrought steel airfoil section, the intimate bond comprising the wrought airfoil section on one side and the sintered skeleton body of the foot section and its contained infiltrant metal on the other side.

4. A compressor blade having an airfoil section and a foot section joined and intimately bonded thereto, the airfoil section comprising a preshaped wrought steel member containing an alloying constituent of an atomic interchange bond-promoting element selected from the group consisting of chromium, nickel, aluminum and silicon at least adjacent the surface thereof, the foot section comprising a sintered metal skeleton body of said steel having interconnecting pores distributed therethrough which contain an infiltrant metal having as an alloying constituent the atomic interchange bond-promoting element as contained in said wrought steel airfoil section, the intimate bond comprising the wrought airfoil section on one side and the sintered skeleton body of the foot section and its contained infiltrant metal on the other side.

5. A compressor blade having an airfoil section and a foot section joined and intimately bonded thereto, the airfoil section comprising a preshaped wrought steel member containing an alloying constituent of an atomic interchange bond-promoting element selected from the group consisting of chromium, nickel, aluminum and silicon at least adjacent the surface thereof, the foot section comprising a sintered metal skeleton body of said steel having interconnecting pores distributed therethrough which contain an infiltrant metal having copper as the major constituent and having as a minor alloying constituent an atomic interchange bond-promoting element selected from the group consisting of chromium, nickel, aluminum and silicon as contained in the wrought steel airfoil section, the intimate bond comprising the wrought airfoil section on one side and the sintered skeleton body of the foot section and its contained infiltrant metal on the other side.

6. A compressor blade having an airfoil section and a foot section joined and intimately bonded thereto, the airfoil section comprising a preshaped wrought steel member containing chromium as an alloying constituent at least adjacent the surface thereof, the foot section comprising a sintered metal skeleton body of said chromium-containing steel having interconnecting pores distributed therethrough which contain an infiltrant metal having

7

copper as the major alloying constituent and chromium as the minor alloying constituent, the intimate bond comprising the wrought airfoil section on one side and the sintered skeleton body of the foot section and its contained infiltrant metal on the other side.

7. A compressor blade having an airfoil section and a foot section joined and intimately bonded thereto, the airfoil section comprising a preshaped wrought steel member containing silicon as an alloying constituent at least adjacent the surface thereof, the foot section comprising a metal skeleton body of said silicon-containing steel having interconnecting pores which contain an infiltrant metal having copper as the major alloying constituent and silicon as the minor alloying constituent, the intimate bond comprising the airfoil section on one side and the skeleton body of the foot section and its contained infiltrant metal on the other side.

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1,995,451
2,000,692
2,063,706
2,198,240
2,198,254
2,300,302
2,309,828
2,353,693
2,377,882
2,382,273
2,431,660
2,479,057
2,520,373

574,440
629,326

8

Handler ----- Mar. 26, 1935
Dimberg ----- May 7, 1935
Soderberg ----- Dec. 8, 1936
Boegehold ----- Apr. 23, 1940
Koehring ----- Apr. 23, 1940
Morin ----- Oct. 27, 1942
Dalby ----- Feb. 2, 1943
Church ----- July 18, 1944
Hensel et al. ----- June 12, 1945
Thielemann ----- Aug. 14, 1945
Gaudenzi ----- Nov. 25, 1947
Bodger ----- Aug. 16, 1949
Price ----- Aug. 29, 1950

FOREIGN PATENTS

Great Britain ----- Jan. 4, 1946
Great Britain ----- Sept. 26, 1949

References Cited in the file of this patent

UNITED STATES PATENTS

20

1,528,581 Steenstrup ----- Mar. 3, 1925
1,547,836 Steenstrup ----- July 28, 1925
1,891,612 Schmidt ----- Dec. 20, 1932