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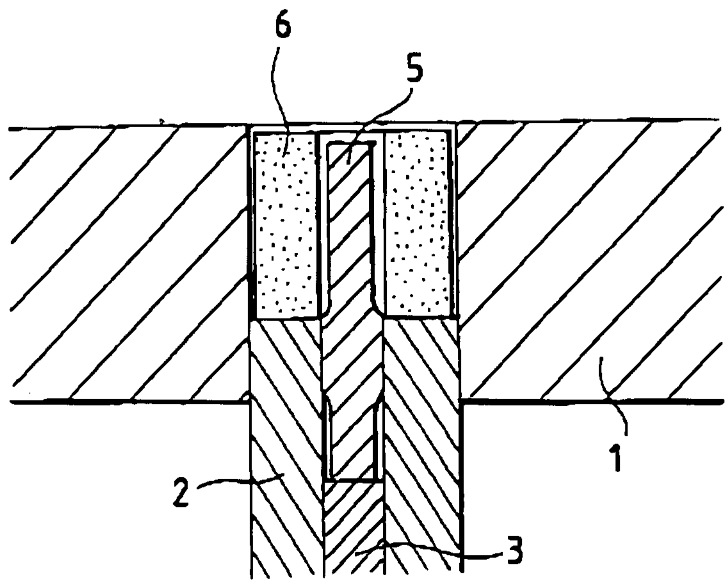
(54) Method of manufacturing a rotor made of aluminum powder alloy having a steel shaft.

(57) A steel shaft is disposed in a forging metallic die, and aluminum alloy powder or its preliminarily formed body is charged in the metallic die around the steel shaft. The aluminum alloy powder or its preliminarily formed body is forged so that a rotor of aluminum powder alloy is manufactured, and at the same time, the rotor is connected and fixed to the shaft.

FIG. 1



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BACKGROUND OF THE INVENTION

The present invention relates to a method of manufacturing a rotor made of aluminum powder alloy having a steel shaft used for an air compressor and the like.

The weight of a rotor used for a compressor and the like is required to be low, and the mechanical strength thereof is required to be high. Therefore, a rotor made of aluminum powder alloy is used, which is manufactured from aluminum alloy powder by means of powder metallurgy. That is, aluminum alloy powder made by the quenching solidification method is used, and solidified by means of sintering, forging or the like so as to manufacture a rotor made of aluminum powder alloy.

The thus manufactured rotor made of aluminum powder alloy is connected and fixed by various methods to a steel shaft which has been differently made. Examples of commonly used connecting methods are: a hot upsetting method in which a rotor, the size of which is a little larger than a predetermined one, is disposed around a shaft in a metallic die, and then the rotor is compressed at a raised temperature so that the rotor can be connected and fixed to the shaft; a press-fitting method in which the inner circumferential surface of a rotor and the outer circumferential surface of a shaft are subjected to serration processing, and then the shaft is mechanically fitted onto the inner circumferential surface of the rotor so that the shaft is fixed to the rotor; and a shrinkage fitting method in which a heated rotor is fitted to a shaft and then cooled so that the rotor and shaft are connected and fixed to each other by using a difference between the thermal expansion coefficients.

In the conventional connecting methods described above, the rotor made of aluminum powder alloy and the steel shaft are differently manufactured, and further not only the shaft but also the inner circumferential surface of the rotor must be machined so that the size and configuration can be appropriately adjusted. Accordingly, the conventional connecting methods are disadvantageous in that the number of manufacturing processes is increased and the cost is high. Especially, in the case of the press-fitting method, the complicated serration processing is required, and the serration processing is one of the main reasons of high cost.

Furthermore, according to the conventional connecting methods, it is difficult to completely connect the aluminum powder alloy rotor with the steel shaft, and a gap tends to be formed on a connection interface between the rotor and the steel shaft. For this reason, the connecting strength is low. In the case where the hot upsetting method is adopted, an end surface of the rotor is subjected to plastic deformation and an amount of the plastic deformation is large. Accordingly, this method is disadvantageous in that cracks tend to occur in the rotor.

SUMMARY OF THE INVENTION

The present invention has been made in view of the circumstances of the conventional methods. It is an object of the present invention to provide a method of manufacturing a rotor made of aluminum powder alloy having a steel shaft characterized in that: the steel shaft is connected and fixed to the rotor made of aluminum powder alloy simultaneously when the aluminum powder alloy rotor is manufactured, so that the number of manufacturing processes is reduced and accordingly the cost is reduced; the occurrence of cracks is avoided in the process of connection; and the connecting strength of the rotor and shaft can be enhanced.

In order to accomplish the above object of the present invention, the present invention provides a method of manufacturing a rotor made of aluminum powder alloy having a steel shaft comprising the steps of: disposing a steel shaft in a forging metallic die; charging aluminum alloy powder or a preliminarily formed body of aluminum alloy powder into the metallic die around the shaft; and forging the aluminum alloy powder or the preliminarily formed body so that a rotor of aluminum powder alloy is manufactured and at the same time the rotor and the shaft are connected and fixed to each other.

According to the present invention, when the aluminum alloy powder or its preliminarily formed body is forged, the rotor made of aluminum powder alloy is manufactured, and at the same time the rotor made of aluminum powder alloy is integrally connected with and strongly fixed to the steel shaft in the same process. Consequently, compared with the conventional methods, the rotor made of aluminum powder alloy having a steel shaft can be manufactured with the reduced number of the manufacturing processes and with the reduced cost.

In the case of the rotor of aluminum powder alloy manufactured by the above described method of the present invention, it is not necessary for the inner circumferential surface of the rotor to be subjected to cutting. Accordingly, no traces of cutting are left on the inner circumferential surface of the rotor, and further the inner circumferential surface of the rotor is deformed and solidified along the outer circumferential surface of the steel shaft by forging, so that the inner circumferential surface of the rotor is connected with and fixed to the outer circumferential surface of the steel shaft without leaving any gaps. Consequently, the rotor that has not been damaged at all is connected with the steel shaft through the largest connecting area. Therefore, the connecting strength can be greatly enhanced compared with that of the conventional method. When aluminum alloy powder or its preliminarily formed body is forged at a raised temperature, the connecting strength can be further enhanced by the effect of shrinkage fitting provided by the cooling after forging operation has been completed.

Especially when the steel shaft is forged while it is preliminarily heated to a temperature of 100°C or higher, and below the annealing temperature of the shaft, a reaction layer of aluminum and iron is formed on the connection interface between the outer circumferential surface of the shaft and the inner circumferential surface of the aluminum powder alloy rotor, so that a stronger connection can be accomplished. Incidentally, an oxide film is formed on the outer circumferential surface of the steel shaft in a process of heat treatment or the like. When at least the oxide film existing on the surface where the steel shaft is connected with the aluminum powder alloy rotor, is previously removed by means of acid cleaning or the like, it is possible to facilitate the formation of the reaction layer.

When roughness in which a difference between the top and bottom is not less than 0.5 mm is formed at least on the outer circumferential surface of the steel shaft where it is connected with the aluminum powder alloy rotor, or when the surface of the connecting portion is made rough in such a manner that the surface roughness R_{max} according to JIS B 0601 is not less than 0.8S, the connecting strength can be effectively enhanced.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view showing a condition in which a preliminarily formed body of aluminum alloy powder and a steel shaft are inserted into a forging metallic mold in the method of the present invention,
Fig. 2 is a sectional view showing a condition in which forging operation of aluminum alloy powder has been completed in the method of the present invention,
Fig. 3 is a sectional view showing a condition in which a rotor made of aluminum powder alloy having a steel shaft is discharged from the forging metallic die in the method of the present invention, and
Fig. 4 is a perspective view showing a method of measuring the slippage torque between the rotor and shaft.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described with reference to the accompanying drawings.

As raw material powder, aluminum alloy powder of 5 types of composition was prepared for rotors, and each aluminum alloy powder was pressurized and formed into a preliminarily formed cylindrical body in which the outer diameter was 65 mm, the inner diameter was 17 mm, and the length was 60 mm. On the other hand, as a shaft to which the rotor was connected and fixed, a shaft made of black molybdenum steel was prepared, in which the outer diameter of the connecting portion was 15 mm and the overall length was 135 mm.

[TABLE 1]

Number	Composition of Rotor (weight %)
(1)	Al-17Si-5Fe
(2)	Al-10Si-5Fe-6Ni
(3)	Al-25Si-2.5Cu-1Mg
(4)	Al-40Si
(5)	Al-20Si-7.5Ni

As illustrated in Fig. 1, a preliminarily formed body 6 of Al alloy powder was charged onto an upper portion of a lower punch 2 inside a forging metallic die 1 while the preliminarily formed body 6 was heated to a temperature immediately below the eutectic temperature of Al alloy. Also, a steel shaft 5 was inserted onto an upper portion of a core rod 3 inside the lower punch 2. With respect to the steel shaft 5, the following conditions were variously changed: the shaft temperature; the difference between the top and the bottom of roughness on the connecting portion of the shaft where the shaft is connected to the rotor; and the surface roughness R_{max} of the connecting portion of the shaft. Further, some of the steel shafts were subjected to acid cleaning for removing the oxide films formed on the surfaces, and others were not subjected to acid cleaning.

Next, as illustrated in Fig. 2, the preliminarily formed body 5 was subjected to hot forging by an upper punch 4 and the lower punch 2 with a forging pressure of 7 to 10 ton/cm^2 so that the preliminarily formed body 5 was solidified to a density of 100%. In this way, a rotor 7 of Al powder alloy of which the composition is shown in Table 1 was made. After that, as illustrated in Fig. 3, the lower punch 2 and the core rod 3 were raised and the rotor 7 made of Al powder alloy was recovered. The outside diameter of each rotor 7 of Al powder alloy obtained in this way was 66 mm, and the length was 45 mm. Each rotor was connected and fixed to the steel shaft 5.

By the test method shown in Fig. 4, slippage torque of the thus obtained rotor of Al powder alloy having a steel shaft was measured in the following manner: After the rotor 7 made of Al powder alloy had been fixed to a rotor mount 8, the steel shaft 5 was rotated with a torque wrench 9, and the slippage torque of the steel shaft 5 was measured when the steel shaft 5 was rotated. The results of the measurement are shown in Table 2 together with the shaft temperature, the difference between the top and the bottom of roughness on the shaft surface, the surface roughness R_{max}, and the existence of an oxide film.

As a comparative example, the rotor of Al powder alloy of the same size and composition as those described above and the steel shaft were separately made, and the inner circumferential surface of the rotor and the outer circumferential surface of the shaft were subjected to serration processing, and then the shaft was press-fitted into the rotor heated to a temperature immediately below the eutectic temperature of Al alloy, and the rotor and shaft were cooled so as to be connected and fixed to each other. With respect to the conventional rotor of Al powder alloy having a steel shaft which was manufactured using both the press-fitting and the shrinkage fitting methods, slippage torque was measured in the same manner as described above, and the results of measurement are shown in Table 2.

[TABLE 2]

Surface condition of the shaft						
Smpl No.	Compo. of rotor	Shaft temp. (°C)	Surface roughness (R_{max})	Difference of hight in roughness (mm)	Existence of oxide film	Slippage torque (kg·m)
1	(1)	R. T.	2.0S	0.5	No	98
2-1	(1)	200	2.0S	0.5	No	152
2-2	(2)	ditto	ditto	ditto	ditto	170
2-3	(3)	ditto	ditto	ditto	ditto	163
2-4	(4)	ditto	ditto	ditto	ditto	111
2-5	(5)	ditto	ditto	ditto	ditto	139
3-1	(1)	300	0.3S	0.5	No	107
3-2	(2)	ditto	ditto	ditto	ditto	125
4-1	(1)	300	6.0S	0.5	No	139
4-2	(2)	ditto	ditto	ditto	ditto	156
4-3	(3)	ditto	ditto	ditto	ditto	150
4-4	(4)	ditto	ditto	ditto	ditto	102
4-5	(5)	ditto	ditto	ditto	ditto	112
5	(1)	300	2.0S	≈0	No	84
6	(1)	300	2.0S	0.5	Yes	109
7-1	(1)	550	2.0S	0.5	No	158
7-2	(2)	ditto	ditto	ditto	ditto	184
7-3	(3)	ditto	ditto	ditto	ditto	159
Compa	(1)	R. T.	-	0.1	Yes	60

According to the results shown in Table 2, the following can be recognized: concerning each of the sample Nos. 1 to 7 of the rotor made of Al powder alloy having a steel shaft of the present invention, slippage torque was much larger than that of the comparative example manufactured by the conventional method, and the connecting strength of the shaft and rotor was greatly improved. Especially, improvements in the connecting strength were greatly affected by the preliminary heating of the shaft and the configuration of roughness formed on the shaft surface. With respect to the sample Nos. 2 to 7 in which the shafts were preliminarily heated, a section of the connecting portion of the shaft and rotor was observed using a scanning type electron microscope. As a result, existence of the reaction layer of Al-Fe was recognized in all the sections.

Further, 100 pieces of rotors made of Al powder alloy having a steel shaft of the sample No. 7 (3 types) of the present invention were manufactured, and also 100 pieces of rotors made of Al powder alloy having a steel shaft of the comparative example were manufactured so as to investigate the percent of defective product. In the comparative example, the percent of defective product due to the cracks of rotors was 2%. On the other hand, in the sample No. 7 of the present invention, there was no occurrence of defective products.

According to the present invention, simultaneously when the rotor made of aluminum powder alloy is manufactured by means of forging, it can be connected and fixed to the steel shaft without leaving any gaps. Accordingly, redundant manufacturing processes can be omitted and manufacturing cost can be reduced. At the same time, the rotor is not cracked in the process of connection, and the connecting strength of the rotor and shaft of the present invention can be greatly enhanced as compared with the conventional rotor and shaft.

Claims

1. A method of manufacturing a rotor made of aluminum powder alloy having a steel shaft, comprising the steps of:
   disposing a steel shaft in a forging metallic die;
   charging aluminum alloy powder or a preliminarily formed body of aluminum alloy powder into said metallic die around said shaft; and
   forging said aluminum alloy powder or said preliminarily formed body so that a rotor made of aluminum powder alloy is manufactured and at the same time said rotor is connected and fixed to said steel shaft.

2. The method of manufacturing a rotor made of aluminum powder alloy having a steel shaft according to claim 1, wherein the step of forging is performed while said steel shaft is heated to a temperature not less than 100°C and less than an annealing temperature of said steel shaft.

3. The method of manufacturing a rotor made of aluminum powder alloy having a steel shaft according to claim 1, wherein roughness is formed at least on a connecting portion of an outer circumferential surface of said steel shaft where the outer circumferential surface of said steel shaft is connected with said rotor made of aluminum powder alloy, said roughness being formed in such a manner that a difference between a top portion and a bottom portion of the roughness is not less than 0.5 mm.

4. The method of manufacturing a rotor made of aluminum powder alloy having a steel shaft according to claim 1, wherein surface roughness R_{max} according to JIS B 0601 of at least a connecting portion of an outer circumferential surface of said steel shaft where the outer circumferential surface of said steel shaft is connected with said rotor made of aluminum powder alloy, is not less than 0.8S.

5. The method of manufacturing a rotor made of aluminum powder alloy having a steel shaft according claim 1, wherein an oxide film, which exists at least on a connecting portion of an outer circumferential surface of said steel shaft where the outer circumferential surface of said steel shaft is connected with said rotor made of aluminum powder alloy, is removed before the step of disposing.

6. The method of manufacturing a rotor made of aluminum powder alloy having a steel shaft according to claim 2, wherein a reaction layer of aluminum and iron is formed in a connecting interface where an outer circumferential surface of said steel shaft is connected to an inner circumferential surface of said rotor made of aluminum powder alloy as a result of the step of forging.

FIG. 1

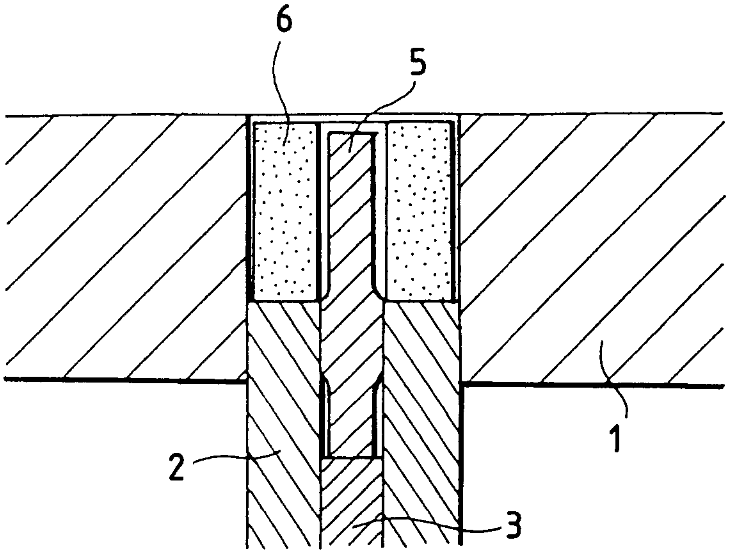


FIG. 2

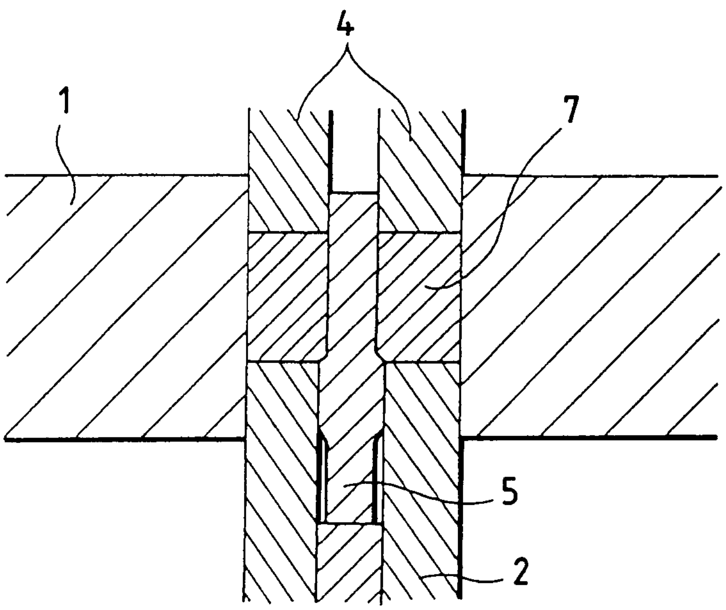


FIG. 3

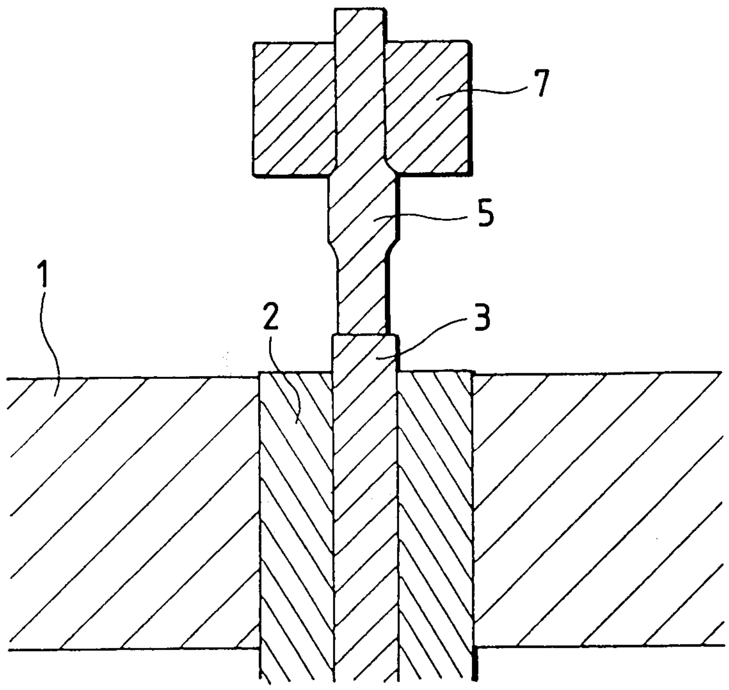
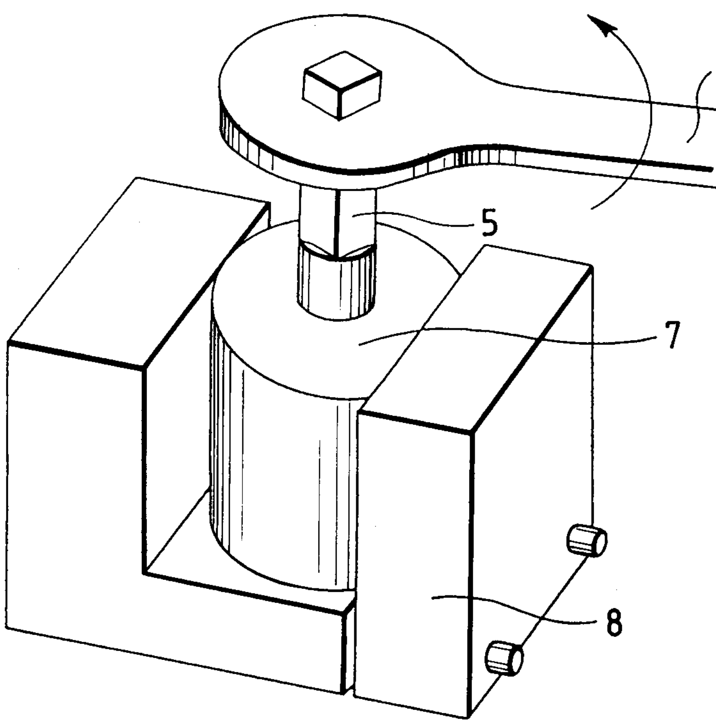


FIG. 4



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EUROPEAN SEARCH REPORT

Application Number
EP 94 11 1322

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	DATABASE WPI Section Ch, Week 8908, Derwent Publications Ltd., London, GB; Class M22, AN 89-058609 & JP-A-1 011 914 (SUMITOMO ELEC IND KK) 17 January 1989 * abstract *	1-6	B22F7/08 B22F3/15
Y	US-A-3 962 772 (J.HALLER ET AL) * abstract *	1-6	
A	EP-A-0 034 847 (METALLGESELLSCHAFT A.G.) * claims 6,9,10 *	6	
A	DATABASE WPI Section Ch, Week 8837, Derwent Publications Ltd., London, GB; Class M22, AN 88-260899 & JP-A-63 189 608 (SUMITOMO ELEC IND KK) 5 August 1988 * abstract *	1-6	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	EP-A-0 151 103 (VEW) * claim 4; example 3 *	1-6	B22F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	16 November 1994	Schruers, H

CATEGORY OF CITED DOCUMENTS

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