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(54) POWDER FOR THE POWDER METALLURGICAL MANUFACTURE OF SOFT MAGNETIC COMPONENTS

(71) We, HÖGANÄS AB, of Fack S-263 01 Höganäs, Sweden, a Swedish Joint Stock Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The invention relates to a powder for the powder metallurgical manufacture of soft magnetic components, and particularly concerns highly pure iron powders having large particle size with the addition of a phosphorus containing powder, especially intended for the powder metallurgical manufacturing of components satisfying great demands for soft magnetic properties.

Powder metallurgical manufacturing techniques are generally characterised by long series production of components having good dimensional accuracy. The manufacturing sequence is generally started by mixing a metallic powder, for example iron powder, if desired containing alloying elements in powder form, with a lubricant in order to simplify a subsequent compression operation. Thereby the powder mixture is compressed to a green compact, the shape of which approximately or exactly corresponds to the shape of the final component. Thereupon the green compact is heated and is retained at a temperature at which the green compact obtains, by means of sintering, its final characteristics with regard to strength, ductility etc. Basically, materials manufactured in this way differ from materials manufactured by the usual metallurgical way of casting by their porosity. Components satisfying the demands for good soft magnetic properties are usually manfactured from materials having iron as its main component. The most common manufacturing method is that wherein the components are manufactured from a piece of highly pure solid material, for example Armco-iron. However, the powder metallurgical technique is also used for the manufacture of such components because of the advantages that this method offers with regard to the saving of material, dimensional accuracy and the simplified shaping of the components. However, it has hitherto not been possible to obtain the same good soft magnetic properties of materials manufactured by means of powder metallurgy including iron as the main component, as for solid material having a corresponding composition. Substantially, this difference is dependent on the porosity of the material manufactured having the powder metallurgical techniques.

According to the invention there is provided a powder for the powder metallurgical manufacture of soft magnetic components, comprising a highly pure iron powder in which the main portion of the powder has a particle size between 35 and 100 Tyler mesh (417 and 147 μm), less than 5% of the powder has a particle size exceeding 35 Tyler mesh (417 μm) and less than 20% of the powder has a particle size less than 100 Tyler mesh (147 μm), and in which the powder contains as an alloy additive up to 1.5% phosphorus.

Thus the invention makes it possible to obtain with a material manufactured using powder metallurgical techniques, soft magnetic properties which are about the same as the corresponding properties of highly pure solid iron, i.e. by using as the starting material an iron powder having a sieve analysis which is unusual for powder metallurgy in that the particles tend to be coarse. In addition to the fact that the iron powder must be coarse, a very low impurity content is required.

This highly pure iron powder, which is preferably manufactured by atomisation, should have an iron content in excess of 99.8%. Here, as well as in the following, "%" means "weight %". The contents of impurities, which are known to deteriorate the magnetic

properties of iron, should in this iron powder by as low as possible and should preferably be: C <0.01 %, O-total <0.1 %, N <0.005 %. The content of particles greater than 35 Tyler mesh (417 μm) does not exceed 5%, and the content of particles less than 100 Tyler mesh (147 μm) is less than 20%, preferably 10%.

Because of the very low content of particles less than 147 μm, the mechanical properties of components manufactured from this coarse, highly pure iron powder are very low. If a higher strength is desired, it is not possible to increase the content of particles having a size less than 147 μm without simultaneously deteriorating the soft magnetic properties. This problem can be overcome by adding a powdered alloying component to the highly pure coarse iron powder, the alloying component producing, on the sintering, an increased strength without deteriorating the soft magnetic properties of the material thus produced.

It is known that ferrophosphorus in powder form which is mixed with the iron powder types normally used in powder metallurgy and having a particle size which is less than 147 μm, brings about, on sintering, an increased strength. See for example the specification of United Kingdom Patent No. 1427070. However in contradistinction to the prior art and as appears from the following Examples, the addition of ferrophosphorus in powder form to the above highly pure coarse iron powder can make the strength of the sintered material five times higher, thereby not only retaining but even further enhancing the soft magnetic porperties. The total phosphorus content of the mixture should not exceed 1.5%. The maximum increase of the strength is obtained at a content of 0.3 % phosphorus. Preferably, the phosphorus is added as ferro-phosphorus powder.

After compression and sintering at conditions normal in connection with powder metallurgical manufacturing, such a powder mixture produces components having good mechanical properties and soft magnetic properties which are better than those of the corresponding material without phosphorus and dependent on the phosphorus content can be even better than the soft magnetic properties of solid highly pure iron.

The invention is hereinafter described with reference to the following specific Examples.

Example 1

Two iron powders having different particle size distributions were manufactured by atomising a highly pure iron melt, drying, after-reduction and sieving. Chemical analysis of these two iron powders gave the following composition: 0.047% O, 0.004 % N, 0.003 % S, < 0.1 % C and balance Fe. The particles size distributions of these iron powders A and B were as follows:

Iron powder	Sieve analysis Tyler mesh, %:		
	>35	35–100	<100
A	1.3	97.4	1.3
B	0.0	3.6	96.4

These iron powders were mixed with ferrophosphorus containing 15% phosphorus and having a particle size less than 45 μm, to a phosphorus content of 0.45 %. In the following powder A with an additionof 0.45 %. phosphorus is designated C and powder B with an addition of 0.45 % phosphorus is designated D.

The powders A to D, mixed with 0.8 % zinc stearate, were compressed at a pressure of 589 MPa to bars having the dimensions 55×10×10 mm and to tensile test bars. After burning-off the lubricant for 30 minutes at 400°C in air, the bars were sintered in a belt furnace for 60 minutes at 1120°C in hydrogen atmosphere. As the coercive force is a relevant measure as to the soft magnetic properties of a material, this was measured by means of a so-called coercimeter. The four materials showed the following coercive forces:

Material	
A	1.02 Oe
B	1.56 Oe
C	0.89 Oe
D	1.34 Oe

The above results show the great advantages which are obtained when using a coarse iron powder mixed with phosphrous. The low coercive force value of material C is about the same as the coercive force of Armco-iron which is about 0.9 Oe.

It has also been found that at the same time as the coercive force decreases the resistivity of the material increased when phosphorus is added, which results in decreasing eddy current losses, which means that the total magnetic losses are reduced.

The density, the tensile strength and the elongation at rupture appear from the following

table:

Material	Density g/cm³	Tensile strength N/mm²	Elongation at rupture %
A	7.28	~50	~5
B	7.29	184	15.4
C	7.24	254	2.6
D	7.25	400	14.0

The strength properties given in this example show very low values for material A manufactured from iron powder having a low content of particles with a size less than 147 um. From the results it can also be seen that an addition of phosphorus to this powder improves the tensile strength about five times.

The results are shown graphically in Figures 1, 2 and 3 which respectively show coercive force, tensile strength and elongation at rupture as a function of the weight of particles having a size less than 100 Tyler mesh.

Example 2

An iron powder A according to Example 1 was mixed with ferrophosphorus containing 15% phosphorus and having a particle size less than 45µm to phosphorus contents of from 0.3 to 1.5 P. 0.8 % Zn-stearate was added to these mixtures. Test bars were compressed, burned-off and sintered in the same way as described in Example 1. The following results were obtained:

Material	Density g/cm³	Tensile strength N/mm²	Elongation at rupture %
A + 0.30 % P	7.23	265	8.6
A + 0.45 % P	7.24	254	2.6
A + 0.60 % P	7.23	240	0.9
A + 1.00 % P	7.18	234	0.7
A + 1.50 % P	7.15	150	0.5
A + 0 % P acc. to Example 1	7.28	~50	~5

These results show that the tensile strength of sintered bars having iron powder A as the basic material is substantially increased because of the addition of phosporus. The fact that this substantial increase of the tensile strength, which is dependent on the addition of phosphorus has been obtained together with an improvement of the soft magnetic properties appears from the following table and Figures 4 and 5, which illustrate the tensile strength and the coercive force, respectively, as a function of the phosphorus content.

Material	Coercive force Oe
A + 0.30 % P	0.95
A + 0.45 % P	0.89
A + 0.60 % P	0.82
A + 1.00 % P	0.73
A + 1.50 % P	0.85
A + 0 % P acc. to Example 1	1.02

All these coercive force values are very low and show that this material is extremely well suited for components wherein good soft magnetic properties are desired.

WHAT WE CLAIM IS:-

1. A powder for the powder metallurgical manufacture of soft magnetic components, comprising a highly pure iron powder in which the main portion of the powder has a particle size between 35 and 100 Tyler mesh (417 and 147 µm), less than 5% of the powder has a particle size exceeding 35 Tyler mesh (417 µm) and less than 20% of the powder has a particle size less than 100 Tyler mesh (147 µm), and in which the powder contains as an

alloy additive up to 1.5 % phosphorus.

2. A powder according to Claim 1, in which less than 10% of the iron powder has a particle size less than 100 Tyler mesh (147μm).

3. A powder according to Claim 1 or Claim 2, in which the powder contains as an alloy additive between 0.15 and 1.0% phosphorus.

4. A powder according to any preceding claim, in which the phosphorus is added in the form of ferrophosphorus in powder form.

5. A powder according to Claim 4, said ferrophosphorus having a phosphorus content of about 15% and a particle size less than 45μm.

6. A powder for the powder metallurgical manufacture of soft magnetic components, according to claim 1 substantially as hereinbefore described with reference to and as shown in the Examples.

7. A powder for the powder metallurgical manufacture of soft magnetic components, substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

8. A soft magnetic component whenever made from a powder according to any preceding claim.

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1599081 COMPLETE SPECIFICATION
2 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 1

Fig.1.

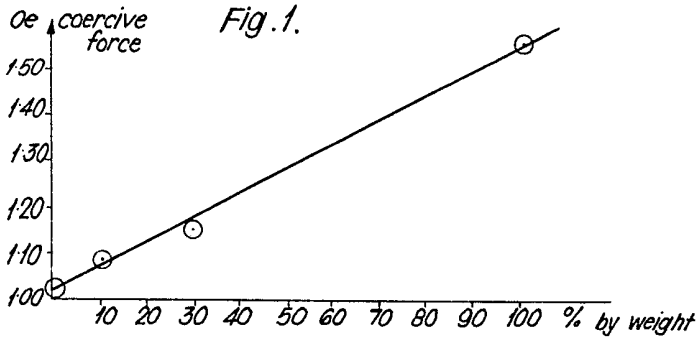


Fig.2.

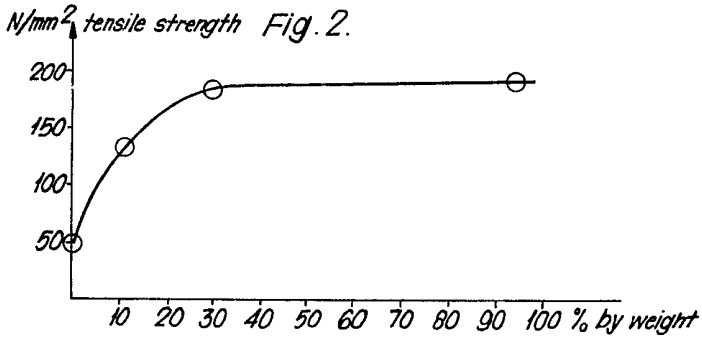
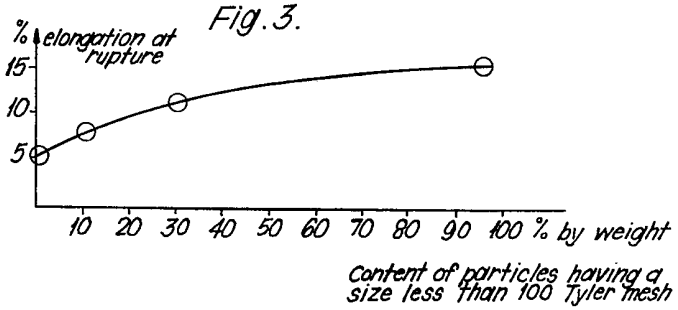


Fig.3.



Content of particles having a size less than 100 Tyler mesh

Fig.4.

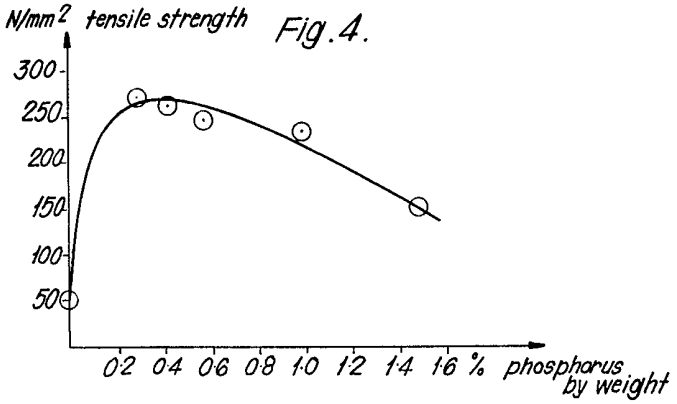
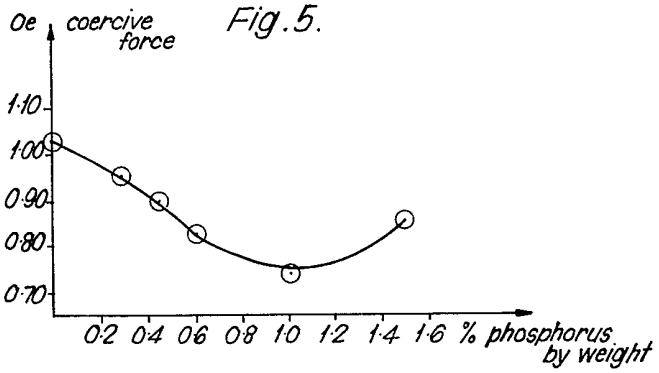

N/mm2 tensile strength
300
250
200
150
100
50
0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6 % phosphorus by weight

Fig.5.


Oe coercive force
1·10
1·00
0·90
0·80
0·70
0·2 0·4 0·6 0·8 1·0 1·2 1·4 1·6 % phosphorus by weight