

DESCRIPTION

OIL-IMPREGNATED IRON-BASED SINTERED BEARING

Technical Field

[0001]

The present invention relates to an oil-impregnated iron-based sintered bearing having an inner circumferential surface for supporting a shaft, and more particularly to an oil-impregnated iron-based sintered bearing suitable for a bearing which supports a shaft rotating normally and reversely such as a paper feeding roller of copying machines.

Background Art

[0002]

Conventionally, bearings made of sintered alloy have been widely used. Since the sintered alloy is a porous material capable of imparting self-lubricating property by the lubricating oil impregnated, the oil-impregnated sintered bearing has good seizure resistance and abrasion resistance, and oil-impregnated sintered bearings of metal matrix containing iron, copper, etc. are widely used. In recent years, the price of copper has soared and the need for bearings with iron as the main component is increasing. However, bearings containing iron as a main component are easily burned and have a disadvantage that the shaft which is a mating part is easily scratched. Particularly, when using a bearing containing iron as a main component in combination with a shaft not subjected to heat treatment and having low hardness, it is necessary to deal with the above phenomena.

[0003]

Under such circumstances, an oil-impregnated iron-based sintered bearing having seizure resistance and attack mitigating property to a mating part, that are comparable to those of an iron-copper-based sintered alloy bearing, has been proposed in the following Patent Literature 1. In this oil-impregnated iron-based sintered bearing, the overall composition of the sintered alloy is composed of, by mass ratio, 2.0 to 9.0 % of copper, 1.5 to 3.7 % of carbon and the balance iron and inevitable impurities. The interior of the bearing has a metallic structure in which pores, a graphite phase, and a copper phase extending in a direction crossing the axial direction of the bearing are dispersed in an iron alloy phase composed of 20 to 85 % (area ratio) of ferrite and the balance pearlite, and the copper phase is exposed on the bearing surface at an area ratio of 8 to 40 %.

Citation List

Patent Literature

[0004]

Patent Literature 1: Japanese Patent Application Laid-Open No. 2010-077474

Summary of Invention

Technical Problem

[0005]

The iron-based sintered bearing of Patent Literature 1 has seizure resistance and attack mitigation to the mating part, which are comparable to those of the oil-impregnated iron-copper-based sintered bearing, as well as excellent wear resistance. However, when applied to a paper feed roller, a head drive motor or the like of a copying machine, the shaft rotates in the normal and reverse directions and the driving time in each of the normal rotation and the reverse rotation is short, so that it is difficult for the oil-impregnated bearing supporting the shaft to form a satisfactory oil film between the shaft and the bearing. If the oil lubricating effect and the mitigation of attack on the mating part are improved so as to be able to cope with such severe operating environments in maintaining lubricity, it can be applied to a wider range of applications.

It is an object of the present invention to further improve the oil lubrication effect and the attack mitigation to mating parts, of the economically advantageous oil-impregnated ferrous sintered bearing, so as to provide an oil-impregnated iron-based sintered bearing which is excellent in retention of oil film formed between the shaft and the bearing and applicable to a wide range of applications.

Technical Solution

[0006]

The inventors of the present invention have studied for an oil-impregnated iron-based sintered bearing to cope with an operating environment where it is difficult to maintain lubricity. As a result, it has been found that, by adjusting the supply capacity of the lubricating oil, an oil-impregnated bearing can be realized which can exhibit good lubrication characteristics even in a situation where it is difficult to maintain the oil film between the shaft and the oil-impregnated bearing.

[0007]

The present invention is based on the above findings, and, according to one aspect of the present invention, the gist of an oil-impregnated iron-based sintered bearing is to have an iron-based sintered bearing having an inner circumferential surface for supporting a shaft, the iron-based sintered bearing having an overall composition comprising, by mass ratio: 2.0 to 9.0 % copper; 0.5 to 1.3 % carbon; and the balance of iron and unavoidable impurities, and the iron-based sintered bearing having a density of 5.3 to 5.7 Mg/m³ and an air permeability of 70×10^{-11} to 200×10^{-11} cm², wherein the inner circumferential surface of the iron-based sintered bearing comprises, by area ratio: 8 to 40 % copper phase; 25 to 55 % pores; 1 to 5 % graphite phase; and the balance iron base, and the iron base has a metallographic structure which includes 20 % by area ratio or more of ferrite.

[0008]

It is suitable for the oil-impregnated iron-based sintered bearing that, on the inner

circumferential surface of the iron-based sintered bearing, an area occupied by pores having a circle equivalent diameter of 70 μm or more is 70 % or more of the area of all the pores. Moreover, it is more suitable that, on the inner circumferential surface of the iron-based sintered bearing, an area occupied by pores having a circle equivalent diameter of 70 μm or more is 70 % or more, with respect to the area of all the pores, an area occupied by pores having a circle equivalent diameter of 45 μm or more and of less than 75 μm is 0.1 to 10 %, and the balance area is occupied by pores having a circle equivalent diameter of less than 45 μm .

Advantageous Effects of Invention

[0009]

Lubricity of the oil-impregnated iron-based sintered bearing can be maintained even in severe operating environments and it has an exceptional effect that it can exhibit good lubrication characteristics even in applications where it is difficult to maintain an oil film such that a shaft rotating normally and reversely is supported and the rotating motion is changed in a short time, thus it is possible to expand the applicable range of the oil-impregnated iron-based sintered bearings to paper feed rollers, head drive motors, etc. of copying machines.

Mode for Carrying Out the Invention

[0010]

As a method for further improving oil lubricity and attack mitigation to a mating part in oil-impregnated iron-based sintered bearings, it is important that both of the supply ability for supplying lubricating oil to the sliding surface (that is, the inner circumferential surface of the bearing) and the retention of the oil film on the sliding surface are compatible. In an operating environment in which the rotating shaft is rotated in both normal and reverse directions and the driving times for normal rotation and reverse rotation are short, it is difficult to hold the oil film formed between the inner circumferential surface of the bearing and the shaft, so it is considered that, if the balance is shifted so as to strengthen the supply of the lubricating oil, the oil film can be easily held. In accordance with this, the air permeability and the density of the sintered bearing that are directly related to the supply capability of the lubricating oil are specified. Furthermore, by focusing on the state of the pores exposed on the inner circumferential surface of the bearing, a pore diameter distribution at which it is easy to achieve both supply of the lubricating oil to the inner circumferential surface and the holding of the oil film is specified. In this way, the metallographic structure of the sintered bearing is designed so as to have air permeability and a pore diameter distribution capable of achieving compatibility between the supply capacity of lubricating oil and the oil film retention, depending on the use environment of the bearing.

[Overall composition of oil-impregnated iron-based sintered bearing and metallic structure of inner circumferential surface of bearing]

The oil-impregnated iron-based sintered bearing of the present invention has, as a main

component, an iron-based sintered bearing having an overall composition comprising, by mass ratio: 2.0 to 9.0 % of Cu; 0.5 to 1.3 % of C; and the balance Fe and inevitable impurities. The iron-based sintered bearing is obtained by: mixing an iron powder, a copper powder and a carbon powder at the above composition ratio and blending, if necessary, a forming lubricant such as stearate salts to prepare a mixed powder; using it as a raw material powder for compaction to press and form it in the shape of a bearing; and sintering the green compact formed. An oil-impregnated iron-based sintered bearing obtained by impregnating the iron-based sintered bearing with lubricating oil supports a rotating shaft on its inner circumferential surface to function as a bearing.

[0011]

The iron-based sintered bearing is constituted by an iron base, and the iron base has a mixed phase structure of a ferrite phase and a perlite phase or has a single phase structure of ferrite. In iron-based sintered bearings, if the ferrite phase having a lower hardness than the pearlite phase is dispersed in the iron base, it is advantageous to alleviate the attack to the mating part. From this viewpoint, in the present invention, the composition of the sintered bearing is adjusted within the above range by compounding at the time of preparing the raw material powder so that the area ratio of the ferrite phase in the iron base of the iron-based sintered bearing is 20 % or more. Reduced iron powder is used as the iron powder that is the raw material of the iron base, and those having an average particle size of about 75 to 150 μm may be favorably used, and those of about 100 μm are particularly preferable.

[0012]

Cu (copper) is dispersed in the iron base as a soft copper phase at the time of sintering, contributing to the familiarity of the oil-impregnated iron-based sintered bearing and mitigation of the counterpart attacking property. However, as the amount of Cu in the whole composition increases, the raw material cost increases by that amount. For this reason, in the oil-impregnated iron-based sintered bearing of the present invention, the technique of the above-mentioned Patent Literature 1 is used with regard to the forming of the green compact so that the copper powder concentrates in the vicinity of the inner circumferential surface of the bearing. Specifically, Cu is introduced in the form of a flat copper powder, whereby when the raw material powder falls in the die cavity, the flat copper powder gathers around the core rod into the state where the copper powder adheres to the periphery of the core rod. Therefore, when the raw material powder in the die cavity is compacted, the copper powder is intensively present on the inner circumferential surface of the green compact. In other words, when a flat copper powder is used as the Cu raw material, it is possible to secure the amount of the copper phase exposed on the inner circumferential surface of the bearing even if the amount of Cu contained in the raw material powder is small. Therefore, even if the amount of Cu in the overall composition is small, the amount of copper phase exposed on the inner circumferential surface of the bearing, which is required to have sliding characteristics, is larger than the inside of the bearing, so that it is possible to enjoy the familiarity with copper while suppressing raw material cost by reducing the amount of Cu in the bearing and the overall composition. Thus, by utilizing the technique of Patent Literature 1, it is possible to prepare an

oil-impregnated iron-based sintered bearing with such an inner circumferential surface that the copper phase is made at an area ratio of 8 to 40 % with respect to the entire inner circumferential surface, even if the amount of Cu in the overall composition of the iron-based sintered bearing is 2.0 to 9.0 % by mass ratio. A flat copper powder having a particle size of about 20 to 150 μm can be suitably used. Copper powder having a small particle size tends to enter the gap between iron particles, and excessively large copper powder becomes difficult to be unevenly distributed around the core rod. The ratio of the particle diameter to the thickness is preferably about 2.5 to 20.

[0013]

C (carbon) partially diffuses to the iron base at the time of sintering and contributes to the formation of the pearlite phase in the iron base, and the remainder functions as a solid lubricant while dispersing as a free graphite phase in the metallic structure (mainly in the pores) to mitigate the friction with the shaft on the inner circumferential surface. In order to obtain this effect, the C content in the overall composition is set to 0.5 mass% or more so that the amount of the graphite phase exposed on the inner circumferential surface of the bearing becomes 1 % or more in terms of the area ratio with respect to the inner circumferential surface. On the other hand, in a paper feed roller of copying machines, etc. or a printer head drive motor, the shaft to be supported rotates in both normal and reverse directions, and the driving time of each of the normal rotation and the reverse rotation is short. In such an application, the graphite tends to drop off from the inner circumferential surface of the bearing due to friction with the shaft. Therefore, the amount of C in the overall composition is limited to 1.3 mass% or less so that the amount of the graphite phase exposed on the inner circumferential surface of the bearing becomes 5 % or less in terms of the area ratio with respect to the inner circumferential surface of the bearing. When graphite powder having an average particle size of about 40 to 80 μm is used, it is preferable in the viewpoints of diffusion to the base, sliding characteristics and the like.

[0014]

An iron-based sintered bearing is obtained by sintering a green compact that is obtained by the compaction of the raw material powder prepared as described above into a bearing shape in a die cavity. The sintering temperature is preferably set to about 950 to 1,030°C. If the sintering temperature is low, the amount of ferrite in the iron base becomes excessive and the hardness is insufficient, and the wear amount when used as a bearing increases. If the sintering temperature is high, the amount of pearlite increases and the hardness is excessive, and when used as a bearing, the wear amount of the shaft increases. And the wear amount of the bearing itself also increases. As the sintering atmosphere gas, a non-oxidizing gas such as hydrogen/nitrogen mixed gas, cracked ammonia gas, converted gas or the like is used. The obtained iron-based sintered bearing is appropriately subjected to sizing and impregnated with lubricating oil, whereby an oil-impregnated iron-based sintered bearing can be obtained.

[Density and air permeability of iron-based sintered bearing]

As the air permeability (permeability, unit: 1 D (darcy) that substantially equals $10^{-12} \text{ m}^2 = 10^{-8} \text{ cm}^2$) of the sintered bearing is higher, the oil-impregnated sintered bearing has higher supply capacity of

the lubricating oil. However, on the other hand, when the air permeability is excessively high, the pressure of the oil film formed between the shaft and the inner circumferential surface of the bearing tends to leak easily, so that the oil retention property deteriorates and good lubrication characteristics cannot be obtained. For this reason, it is important to adjust the air permeability of the sintered bearing according to the application so as to obtain suitable lubricating oil supply and oil film pressure. This can be adjusted by the density of the sintered bearing. In applications with operating environments where a shaft rotating normally and reversely is supported and each driving time for normal rotation and reverse rotation is short, it is advisable to prepare the sintered bearing so that the density is in a range of 5.3 to 5.7 Mg/m³ and the air permeability is in a range of 70×10^{-11} to 200×10^{-11} cm². The density of the sintered bearing can be adjusted to a desired value by changing the amount of raw material powder to be charged into the die cavity and adjusting the compression ratio at the time of powder compacting.

[0015]

In order to further improve the lubrication characteristics in an application with the operating environment where a shaft rotating normally and reversely is supported and each driving time for normal rotation and reverse rotation is short, it is preferable to prepare the sintered bearing so that the pores are formed in the inner circumferential surface of the bearing in an area ratio of 25 to 55 % with respect to the inner circumferential surface of the bearing. For this practice, it is possible to use the adjustment of the particle size distribution of the powder used as a raw material and the final compression processing (sizing, coining) after sintering, and the pores that open to the surface can be reduced by the final compression processing.

[0016]

[Size and amount of pores of oil-impregnated iron-based sintered bearing]

Although related to the above-mentioned density and air permeability, the large pores contribute to the supply capacity of the lubricating oil in the oil-impregnated iron-based sintered bearing, but at the same time, they act disadvantageously in oil retention, making difficult to maintain good lubrication characteristics. On the other hand, the small pores dispersed in the iron base enhances the oil retaining ability on the inner circumferential surface of the bearing and contributes to the improvement of oil retention in the oil film formed on the shaft and the inner circumferential surface of the bearing.

[0017]

From this viewpoint, it is preferable, in the oil-impregnated iron-based sintered bearing of the present invention, to balance the supply capability of the lubricating oil and the oil retention by adjusting the amount of large pores for supplying the lubricating oil and the amount of small pores dispersed in the iron base. Regarding this point, the size of the pores is evaluated by the equivalent circle diameter (area circle equivalent diameter: Heywood diameter) in the present invention. The equivalent circle diameter is the diameter of the perfect circle when converted into a perfect circle having an area equal to the area to be measured, and it can be determined using commercially available image analysis software, based on the image observed by the optical microscope. Specifically, it is preferable that large pores, i.e. pores

having an equivalent circle diameter of 75 μm or more, are 70 % or more of the area of all the pores exposed on the inner circumferential surface of the bearing, and the remaining pores are small pores, i.e. pores having an equivalent circle diameter of less than 75 μm .

[0018]

In the oil-impregnated iron-based sintered bearing of the present invention, it is preferable that the oil-impregnated iron-based sintered bearing has pores having an equivalent circle diameter of 75 μm or more which occupy 70 % or more of the area of all the pores, pores having an equivalent circle diameter of 45 μm or more and less than 75 μm which occupy 0.1 to 10 % of the area of all the pores, and pores having an equivalent circle diameter less than 45 μm which occupy the rest of the area of all the pores.

The lubricating oil to be impregnated into the iron-based sintered bearing can be used by appropriately selecting from various lubricating oils in consideration of the application and the operating environment, and one kind or two or more kinds in combination may be used from, for example, mineral oils, synthetic hydrocarbon oils, ester oils and the like. In general, lubricating oils having an ISO viscosity grade of VG 50 to 150 are preferably used.

[Examples]

[0019]

Hereinafter, the present invention will be described in more detail based on examples.

[0020]

(1) Preparation of the bearing

In order to prepare an iron-based sintered bearing, the following powders were prepared.

1. Ore reduced iron powder (average particle diameter: 100 μm)
2. Copper foil powder (average particle diameter: 50 μm)
3. Natural graphite powder (average particle size: 60 μm)
4. Zinc stearate

[0021]

To 93.5 parts by mass of the above iron powder, 5 parts by mass of the copper powder and 1.5 parts by mass of the graphite powder were added. Then, to 100 parts by mass of these mixed powders, 0.6 parts by mass of zinc stearate was added as a forming lubricant and mixed together, whereby a raw material powder was prepared.

[0022]

The above raw material powder was charged into a circular tube-shaped cavity and subjected to compression forming into a circular tubular green compact having a cylindrical inner circumferential surface. The obtained green compact was sintered and sized to obtain an iron-based sintered bearing. The sintering was carried out by heating to 1,000 $^{\circ}\text{C}$ in an atmosphere of cracked ammonia gas, and the sizing was carried out by an ordinary method to the extent that sealing of the pores by the plastic flow did not proceed on the inner circumferential surface. In order to produce sintered bearings of the same size

with different densities in the range of 5.1 to 5.9 Mg/m³, the pressurizing operation during the forming was set based on the condition that the median density of the bearing was 5.5 Mg/m³ and the median value of the effective porosity was 29 %, and the amount of the raw material powder to be filled into the cavity was adjusted so as to obtain the density shown in Table 1, whereby oil-impregnated sintered bearings of Sample Nos. 1 to 4 were prepared. Oil-impregnated sintered bearing samples of Sample Nos. 6 to 14 were prepared with the density of the bearing kept constant at 5.5 Mg/m³, by changing the sizing margin of the sizing pin to the inner bore of the bearing during sizing. For each sample number, a plurality of sintered bearing samples were prepared for measurement and testing.

Then the pores of the sintered bearing were impregnated with lubricating oil (mineral oil, viscosity grade ISO VG68) to obtain oil-impregnated sintered bearing samples of Sample Nos. 1 to 14, which were used as test samples in the following test.

[0023]

(2) Evaluation

For each sample number, the air permeability of the sintered body was measured before sizing, and the bearing after the sizing was divided in the axial direction and the inner circumferential surface was observed with an optical microscope. Using the image analysis software (Quick Grain Standard Video produced by INNOTECH CORPORATION), the area ratio of pores was obtained from the image of the inner circumferential surface. Further, for each pore in the image, the equivalent circle diameter was calculated from the area of each pore, and the distribution ratio of pores was determined based on the calculated equivalent circle diameter.

Moreover, the oil-impregnated sintered bearing sample for testing was attached to a housing so that its axial direction was horizontal. Further, installing a motor so that the rotation axis was horizontal, a shaft made of induction-hardened carbon steel S45C was attached to the rotating shaft of the motor. This shaft was inserted with a gap into the inner bore of the oil-impregnated sintered bearing sample attached to the housing, and the bearing was tested by rotating the shaft normally and reversely in a state where a load was applied to the housing in the vertical direction. In the test of the bearing, with setting the shaft rotation speed to 3,000 rpm and setting the load surface pressure to 1 MPa, 20 minutes of operation was performed and the friction coefficient after the end of operation was measured. The evaluation results of the oil-impregnated sintered bearing samples of Sample Nos. 1 to 4 are shown in Table 1, and the evaluation results of the oil-impregnated sintered bearing samples of Sample Nos. 5 to 14 are shown in Table 2.

[0024]

[Table 1]

Sample No.	Density Mg/m ³	Air Permeability $\times 10^{-11}$	Friction Coefficient
1	5.1	220	0.17
2	5.3	200	0.12
3	5.7	70	0.11
4	5.9	50	0.16

[0025]

From the results of the oil-impregnated sintered bearing samples of Sample Nos. 1 to 4, the friction coefficient falls within a low range of 0.11 to 0.12 in each of the oil-impregnated sintered bearing samples of samples Nos. 2 and 3, and occurrence of metal contact has been prevented. On the other hand, those in the oil-impregnated sintered bearing samples of Sample Nos. 1 and 4 are all 0.16 or more, and it is considered that metal contact occurred. That is, it can be said that the balance between supply of lubricating oil and retention of oil film is good in Sample Nos. 2 and 3. Therefore, by setting the density to the range of 5.3 to 5.7 Mg/m³ and the air permeability to the range of 70×10^{-11} to 200×10^{-11} cm², occurrence of metal contact can be suppressed and the friction coefficient can be reduced.

[0026]

[Table 2]

Sample No.	Area Ratio of Pores %	Ratio occupied in Area of Pores %			Friction Coefficient
		$75 \mu m \leq$	$45 \mu m$ to $75 \mu m$	$<45 \mu m$	
5	20.0	72.0	6.6	21.4	0.18
6	25.0	76.5	5.7	17.8	0.13
7	55.0	82.3	5.1	12.6	0.12
8	60.0	88.5	4.7	6.8	0.17
9	40.5	65.0	5.1	19.9	0.17
10	42.0	70.0	5.7	24.3	0.13
11	43.0	93.2	0.05	6.75	0.16
12	42.6	91.5	0.1	8.4	0.13
13	38.4	83.0	10.0	7.0	0.12
14	37.7	78.4	13.0	8.6	0.16

[0027]

From the results of the oil-impregnated sintered bearing samples of Sample Nos. 5 to 8 in Table 2, the friction coefficient falls within a low range of 0.12 to 0.13 in each of the oil-impregnated sintered bearing samples of Sample Nos. 6 and 7, and the occurrence of metal contact has been prevented. However, those in the oil-impregnated sintered bearing samples of Sample Nos. 5 and 8 are all 0.17 or more, and it is considered that metal contact occurred. As in the above, the supply of the lubricating oil and the retention of the oil film are good in the sintered bearing in which the area ratio of the pores is in the range of 25 to 55 %, so that the occurrence of the metal contact is suitably suppressed and the friction coefficient can be reduced.

[0028]

From the results of the oil-impregnated sintered bearing samples of Sample Nos. 9 to 10 in

Table 2, the friction coefficient is low value of 0.13 in the oil-impregnated sintered bearing sample of Sample No.10, and the occurrence of metal contact has been prevented. However, that in the oil-impregnated sintered bearing sample of Sample No. 9 is 0.17, and it is considered that metal contact occurred. As in the above, occurrence of metal contact is suitably suppressed and the friction coefficient can be reduced in the sintered bearings in which large pores having an equivalent circle diameter of 75 μm or more occupy 70 % or more of all the pores in terms of area ratio on the inner circumferential surface.

[0029]

From the result of Sample Nos. 11 to 14 in Table 2, the friction coefficient falls within a low range of 0.12 to 0.13 in the oil-impregnated sintered bearing samples of Sample Nos. 12 and 13, and the occurrence of metal contact has been prevented. However, those in the oil-impregnated sintered bearing samples of Sample Nos. 11 and 14 are the high value of 0.16, and it is considered that metal contact occurred. As in the above, occurrence of metal contact is suitably suppressed and the friction coefficient can be reduced in the sintered bearings in which moderate pores having an equivalent circle diameter of 45 to 75 μm occupy 0.1 to 10 % of all the pores in terms of area ratio.

Industrial Applicability

[0030]

Even in applications where it is difficult to form a good oil film between the shaft and the oil-impregnated bearing such that the shaft is supported to rotate normally and reversely and the rotation turns in a short time drive, good lubrication characteristics are exhibited, so as to be applicable to bearings used in a severe operating environment such as a paper feed roller of a copying machine, a head drive motor and the like.

CLAIMS

[Claim 1]

An oil-impregnated iron-based sintered bearing comprising an iron-based sintered bearing having an inner circumferential surface for supporting a shaft,

the iron-based sintered bearing having an overall composition comprising, by mass ratio: 2.0 to 9.0 % copper; 0.5 to 1.3 % carbon; and the balance of iron and unavoidable impurities, and the iron-based sintered bearing having a density of 5.3 to 5.7 Mg/m³ and an air permeability of 70×10^{-11} to 200×10^{-11} cm²,

wherein the inner circumferential surface of the iron-based sintered bearing comprises, by area ratio: 8 to 40 % copper phase; 25 to 55 % pores; 1 to 5 % graphite phase; and the balance iron base, and the iron base has a metallographic structure which includes 20 % by area ratio or more of ferrite.

[Claim 2]

The oil-impregnated iron-based sintered bearing as set forth in claim 1, wherein, on the inner circumferential surface of the iron-based sintered bearing, an area occupied by pores having a circle equivalent diameter of 70 μm or more is 70 % or more of the area of all the pores.

[Claim 3]

The oil-impregnated iron-based sintered bearing as set forth in claim 1 or 2, wherein, on the inner circumferential surface of the iron-based sintered bearing, an area occupied by pores having a circle equivalent diameter of 70 μm or more is 70 % or more, with respect to the area of all the pores, an area occupied by pores having a circle equivalent diameter of 45 μm or more and of less than 75 μm is 0.1 to 10 %, and the balance area is occupied by pores having a circle equivalent diameter of less than 45 μm.