(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 510 598 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **92106860.7**

(22) Date of filing: **22.04.92**

(51) Int. Cl.5: **C22C 38/36**, C22C 33/02, B22F 3/14, //B22F7/08, B32B15/01,B21B27/00

(30) Priority: **22.04.91 JP 90280/91**

(43) Date of publication of application: **28.10.92 Bulletin 92/44**

(84) Designated Contracting States: **DE FR**

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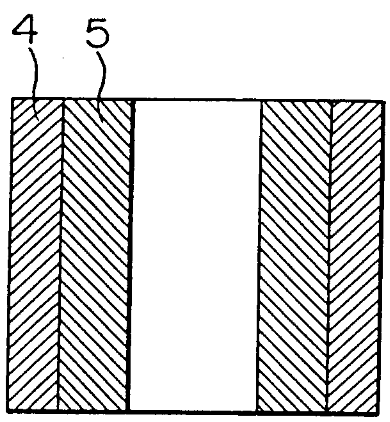
(54) **Wear-resistant compound roll and method of producing same.**

(57) The wear-resistant compound roll having a sintered shell portion (4) having good wear resistance is produced by sintering an alloy powder consisting essentially, by weight, of 1.0-3.5 % of C, 2 % or less of Si, 2 % or less of Mn, 10 % or less of Cr, 3-15 % of W, 2-10 % of Mo, 1-15 % of V, and balance Fe and inevitable impurities, at a temperature equal to or higher than the temperature from which the alloy powder starts to be melted.

FIG. 5



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BACKGROUND OF THE INVENTION

The present invention relates to a wear-resistant compound roll and a method of producing it, and more particularly to a wear-resistant compound roll having a shell portion formed around a core portion, the shell portion being made of a sintered alloy material showing excellent wear resistance, and a method of producing it.

The rolls are required to have roll surfaces suffering from little wear, little surface roughening, little sticking with materials being rolled, less cracks and fractures, etc. For this purpose, cast compound rolls having hard outer surfaces and forged steel rolls having roll body portions hardened by heat treatment, etc. are conventionally used. Depending on applications, various materials and production methods are used for preparing these rolls.

Further, a higher wear resistance is increasingly demanded for rolls, and compound rolls provided with shell portions made of sintered alloys were recently proposed. For instance, Japanese Patent Laid-Open No. 62-7802 discloses a compound roll constituted by a shell portion and a roll core, the shell portion being made from powder of a high-speed steel, a high-Mo cast iron, a high-Cr cast iron, a Ni-Cr alloy, etc., and diffusion-bonded to the roll core by a HIP treatment. Japanese Patent Laid-Open No. 58-128525 discloses a cemented carbide roll and a compound ring roll whose ring portion is made of a cemented carbide.

Japanese Patent Laid-Open No. 58-87249 discloses a wear-resistant cast roll having a composition consisting essentially of 2.4-3.5% of C, 0.5-1.3% of Si, 0.3-0.8% of Mn, 0-3% of Ni, 2-7% of Cr, 2-9% of Mo, 0-10% of W, 6-14% of V, and balance Fe and inevitable impurities. Among the above alloy components, W, Mo and V form metal carbides, contributing to providing the roll with excellent wear resistance. However, since this roll material is produced by casting, it still suffers from the problems that the particle sizes of metal carbides are as large as 50-200 μm, and that the distribution of the metal carbides is microscopically not uniform.

Recently, research has been conducted to provide a compound roll having metal carbide particles whose sizes are extremely small and uniform, by using a HIP method instead of a casting method.

These rolls show improved wear resistance as compared with the conventional cast iron rolls and forged rolls. However, in view of the demand level of wear resistance which is becoming higher recently, these rolls are still insufficient.

To further improve the wear resistance, large amounts of carbide-forming elements are added to roll materials, thereby forming large amounts of high-hardness metal carbides in the roll matrix. Particularly, since vanadium carbide (VC) shows extremely higher hardness than the other metal carbides, the wear resistance of the roll can be remarkably improved by forming VC in the roll matrix.

When the alloy powder containing a large amount of a carbide-forming element (particularly V) is used and subjected to a HIP treatment, fine carbides are precipitated. However, the wearing of the roll is relatively large despite the large amount of VC. Accordingly, such cast rolls are not satisfactory from the aspect of wear resistance and resistance to surface roughening.

OBJECT AND SUMMARY OF THE INVENTION

An object of the present invention is, accordingly, to provide a wear-resistant compound roll having a shell portion made of a sintered alloy showing excellent wear resistance.

Another object of the present invention is to provide a method of producing such a wear-resistant compound roll.

The wear-resistant compound roll according to the present invention has a shell portion produced by sintering an alloy powder consisting essentially, by weight, of 1.0-3.5% of C, 2% or less of Si, 2% or less of Mn, 10% or less of Cr, 3-15% of W, 2-10% of Mo, 1-15% of V, and balance Fe and inevitable impurities, the shell portion containing carbide particles having particle sizes within the range of 3-50 μm in a martensite or bainite matrix.

In the above wear-resistant compound roll, the shell portion may further contain 3-15% of Co. Also, an area ratio of the carbide particles in the metal structure of the sintered shell portion is preferably 15% or more, and among the carbide particles having particle sizes of 0.5 μm or more, the number of the carbon particles having particle sizes of 3 μm or more is 10% or more.

The method of producing a wear-resistant compound roll according to the present invention comprises the steps of (a) charging an alloy powder having a composition consisting essentially, by weight, of 1.0-3.5% of C, 2% or less of Si, 2% or less of Mn, 10% or less of Cr, 3-15% of W, 2-10% of Mo, 1-15% of V, and balance Fe and inevitable impurities, into a metal capsule disposed around a roll core portion; and (b) after evacuation and sealing, subjecting the alloy powder to a HIP (hot isostatic pressing) treatment at a temperature equal to or higher than the temperature from which the alloy powder starts to be melted.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a microphotograph showing the metal structure of a test piece cut out from the shell portion of the compound roll according to the present invention;

Fig. 2 is a cross-sectional view showing an apparatus for producing a wear-resistant compound roll according to the present invention;

Fig. 3 (a) is a schematic view showing the wearing mechanism of the compound roll of the present invention;

Fig. 3. (b) is a schematic view showing the wearing mechanism of the conventional roll;

Fig. 4 is a schematic view showing a heat treatment pattern as one example of heat treatment conditions used in the production of the wear-resistant compound roll of the present invention;

Fig. 5 is a cross-sectional view showing the compound roll;

Fig. 6 is a schematic view for explaining an abrasive wear test method;

Fig. 7 is a graph showing the relation between weight loss by wear and hardness;

Fig. 8 is a cross-sectional view showing another example of a compound roll; and

Figs. 9 is a microphotograph showing the metal structure of the conventional roll.

DETAILED DESCRIPTION OF THE INVENTION

The alloy powder used for producing the shell portion of the compound roll in the present invention has a composition consisting essentially, by weight, of 1.0-3.5% of C, 2% or less of Si, 2% or less of Mn, 10% or less of Cr, 3-15% of W, 2-10% of Mo, 1-15% of V, and balance Fe and inevitable impurities.

In this alloy, C is combined with Cr, W, Mo and V to form hard carbides, contributing to the increase in wear resistance. However, when the carbon content is excessive, too much carbides are formed, making the alloy brittle. Further, C is dissolved in the matrix to show the function of secondary hardening by tempering. However, if C is in an excess amount, the toughness of the matrix is decreased. For these reasons, the C content is 1.0-3.5 weight %. The preferred C content is 1.5-3.0 weight %.

Si has a function of deoxidation, hardening of the alloy matrix, increasing oxidation resistance and corrosion resistance, and improving the atomizability of the alloy. To achieve these effects, the amount of Si is 2 weight % or less. The preferred Si content is 0.2-1 weight %.

Mn is contained in an amount of 2 weight % or less, because it has a function of deoxidation and increasing the hardenability of the alloy. The preferred Mn content is 0.2-1 weight %.

Cr not only contributes to the improvement of wear resistance by forming carbides with C but also enhances the hardenability of the alloy by dissolving into the matrix, and increasing the secondary hardening by tempering. However, when Cr is in an excess amount, the toughness of the matrix is lowered. Accordingly, the Cr content is 10 weight % or less. The preferred Cr content is 3-6 weight %.

W and Mo not only increase wear resistance by combining with C to form M_6C-type carbides, but also are dissolved in the matrix, thereby increasing the hardness of the matrix when heat-treated. However, when they are in excess amounts, the toughness of the alloy decreases, and the material becomes expensive. Accordingly, W is 3-15 weight %, and Mo is 2-10 weight %. The preferred W content is 3-10 weight %, and the preferred Mo content is 4-10 weight %.

V is combined with C like W and Mo. It forms MC-type carbides which have a hardness Hv of 2500-3000, extremely larger than the hardness Hv of 1500-1800 of the M_6C-type carbides. Accordingly, V is an element contributing to the improvement of wear resistance. When the V content is lower than 1 weight %, its effect is too small. On the other hand, when the V content exceeds 15 weight %, the atomizability and workability of the alloy become poor. Accordingly, the V content is 1-15 weight %. The preferred V content is 4-15 weight %.

Since Co is an element effective for providing the alloy with heat resistance, it may be added to the alloy powder. However, when it is in an excess amount, it lowers the toughness of the alloy. Accordingly, Co is preferably 3-15 weight %. The more preferred Co content is 5-10 weight %.

In the production of the alloy powder, an alloy having the above composition is melted and formed into powder by a gas atomization method, etc. The alloy powder obtained by such a method desirably has an average particle size of 30-300 μm.

By using the above alloy powder, it is possible to produce a compound roll having a shell portion with excellent wear resistance, the shell portion being diffusion-bonded to the roll core portion.

The shell portion of the compound roll according to the present invention has a martensite or bainite matrix. Because of this matrix structure, the shell portion shows excellent mechanical strength.

With respect to the core portion of the compound roll, it may be made of any iron-base alloy materials such as cast iron, cast steel, forged steel, etc.

Next, the method of producing the wear-resistant compound roll according to the present invention will be described.

As shown in Fig. 2, the alloy powder "P" obtained by atomization, etc. is charged into a metal capsule 2 disposed around a roll core portion 1. The metal capsule 2 is evacuated through a vent 3 provided in an upper portion thereof and sealed, to keep the inside of the metal capsule 2 in a vacuum state. It is then subjected to a HIP treatment. Incidentally, the metal capsule 2 may be made of steel or stainless steel plate having a thickness of about 3-10 mm.

The HIP treatment is usually conducted at a temperature equal to or higher than the temperature from which the alloy powder starts to be melted (hereinafter referred to as "melting-start temperature"). Specifically, the HIP treatment is conducted at a temperature of 1100-1300°C and a pressure of 9.81 - 14.715 • 10^3 N/cm^2 (1000-1500 atm) in an inert gas atmosphere such as argon, etc. for 1-8 hours, preferably 2-5 hours.

The most important feature of the present invention is that by conducting the HIP treatment at a temperature not lower than the melting-start temperature of the alloy powder, the sizes and distribution of carbides in the alloy matrix of the shell portion of the compound roll are controlled, thereby improving the wear resistance of the compound roll. As is clear from Figs. 1 and 9, which are photomicrographs showing the metal structures of Example 1 and Comparative Example 1, the sizes and distribution of carbides in the alloy matrix vary remarkably depending on the HIP treatment temperature even for the same alloy composition.

At a first glance, Fig. 9, which is a photomicrograph of the metal structure of Comparative Example 1, appears to indicate that fine carbide particles uniformly distributed in the alloy matrix are better than those having larger sizes. However, it has been found that the compound roll whose shell portion has such a metal structure shows poor wear resistance when the compound roll is used for rolling. Fig. 1 verifies that the larger the sizes of the carbide particles in the matrix the higher wear resistance can be obtained.

In this case, the carbide particles contributing to improving the wear resistance of the compound roll have particle sizes of 3 µm or more, as shown in Fig. 1. When the carbide particles distributed in the alloy matrix have particle sizes less than 3 µm as shown in Fig. 9, it is considered that by the wearing mechanism shown in Fig. 3(b) the carbide particles do not substantially contribute to the improvement of the wear resistance of the compound roll. Specifically, when there is a wearing particle 9 in contact with the roll surface, the overall metal structure of the roll is deformed because the carbide particles 11 in the matrix 10 have small particle sizes. Accordingly, wearing of the roll takes place easily. On the other hand, as shown in Fig. 3(a), when the carbide particles 11 dispersed in the roll matrix 10 have particle sizes of 3 µm or more, good wear resistance can be achieved. However, if the particle sizes of the carbide particles exceed 50 µm, severe wearing takes place unevenly at microscopic level from site to site depending on whether there are carbide particles or not.

Even though there are carbide particles having particle sizes of 3 µm or more, the improvement of the wear resistance cannot be expected as long as the amount of the carbide particles is too small. Accordingly, the carbide particles having particle sizes within the range of 3 µm to 50 µm should occupy 15 % or more of the matrix by an area ratio. The preferred area ratio of the carbide particles in the alloy matrix is 20-40 %.

With respect to the particle sizes of the carbide particles, the percentage of the number of the carbide particles having particle sizes of 3 µm or more to the number of the carbide particles having particle sizes of 0.5 µm or more should be 10 % or more. When the above percentage is less than 10 %, the wear resistance of the shell portion is deteriorated. The preferred percentage of the number of the carbide particles having particle sizes of 3 µm or more to the number of the carbide particles having particle sizes of 0.5 µm or more is 10-40 %.

The compound roll having the metal structure meeting the above requirements shows improved wear resistance due to the mechanism shown in Fig. 3 (a). Specifically, even when the wearing particle 9 is brought into contact with the roll surface, the particle 9 is sustained by the large carbide particles 11, preventing the particle 9 from damaging the overall metal structure. By this mechanism, the roll is well protected from wearing.

After the HIP treatment, the metal capsule 2 is removed by a lath. It is then subjected to a heat treatment in the pattern such as shown in Fig. 4. The desired compound roll is obtained after finish working.

The present invention will be described in further detail by means of the following Examples, without any intention of restricting the scope of the present invention.

Example 1, Comparative Example 1

Alloy powder having a composition shown in Table 1 was charged into a cylindrical metal capsule 2 disposed around a roll core portion 1 as shown in Fig. 2. The metal capsule 2 was evacuated through a vent 3 in an upper portion thereof while heating the overall metal capsule 2 at about 500 °C, and the vent 3 was sealed to keep the inside of the metal capsule 2 at about 1.333 • 10^{-3} hPa (1 x 10^{-3} torr). After that, this metal capsule 2 was placed in an argon gas atmosphere and subjected to a HIP treatment at a temperature of 1250 °C and at a pressure of 9.81 • 10^3 N/cm^2 (1000 atm) for 2 hours. Incidentally, the temperature at which the alloy powder started to melt was 1195 °C.

Table 1

Chemical Components of Alloy Powder (weight %)								
C	Si	Mn	Cr	Mo	W	V	Co	Fe
2.5	0.4	0.4	4.0	5.3	8.8	6.9	8.4	Bal.

After the HIP treatment, the outside metal capsule 2 was removed by lathing, and the resulting sample was subject to a heat treatment in the pattern shown in Fig. 4. Thereafter, the compound roll was subjected to finish work to provide a hollow compound roll consisting of a shell portion 4 made of a sintered alloy having an outer diameter of 350 mm and a thickness of 20 mm and a roll core portion 5 having an inner diameter of 250 mm and a length of 400 mm as shown in Fig. 5. This compound roll had a shell portion 4 having a metal structure shown in Fig. 1.

For comparison, a HIP treatment was conducted on the same compound roll as in Example 1 at a temperature of 1170 °C, lower than the above melting-start temperature of 1195 °C, for the same period of time, and the same working as above was then conducted to provide a compound roll of Comparative Example 1. The metal structure of the shell portion of the compound roll of Comparative Example 1 is shown in Fig. 9.

In both compound rolls, the shell portion 4 and the core portion 5 were diffusion-bonded to each other by the HIP treatment. In Figs. 1 and 9, white granular portions are carbide particles. Big differences are appreciated between the carbide particles in Fig. 1 and those in Fig. 9 in the particle size and distribution. The particle sizes and distribution of carbide particles are shown in Table 2.

Table 2

	Particle Size of Carbides (µm)			Area Ratio of Carbides (%)		
	Av.(1)	Min.(2)	Max.(3)	Total Amount of Carbides(4)	Carbides of 3-50 µm	Carbides of 3 µm or More (%)
Example 1	5.2	0.3	18.7	30	22	32
Comparative Example 1	1.0	0.2	2.5	30	0	0

Note: (1) Average particle size.

(2) Minimum particle size.

(3) Maximum particle size.

(4) Carbide particles having particle sizes of 0.5 µm or

more were counted.

Next, the compound rolls produced by the above method were subjected to an abrasive wear test method. For this purpose, a test piece of 10 mm x 10 mm x 15 mm was machined from the shell portion of each compound roll, and subjected to a tempering treatment so that the test pieces 8 had various levels of hardness. As shown in Fig. 6, an emery paper 7 was attached to a test table 6, and the test table 6 was rotated. Each test piece 8 was pushed onto the emery paper 7 under pressure of 598.6 N/mm^2 (60 kg mm^2) for 3 minutes to conduct the wear test. Before and after the wear test, the weight of the test piece was measured to evaluate a weight loss by wearing. The results are shown in Fig. 7. In the figure, the straight line A denotes Example 1 and the straight line B denotes Comparative Example 1.

As is clear from the comparison of the straight line A with the straight line B, the weight loss of the compound roll of the present invention (Example 1) is about one-third that of the compound roll of Comparative Example 1 on the same hardness level. This means that the the compound roll of the present invention (Example 1) is about three times as wear-resistant as the compound roll of Comparative Example 1.

<u>**Example 2, Comparative Example 2**</u>

Two hollow compound rolls each having a shape as shown in Fig. 8 were produced under the same conditions as in Example 1. Each compound roll consisted of a shell portion 4 made of a sintered alloy having the same composition as in Example 1 and having an outer diameter of 400 mm and a thickness of 30 mm, and a roll core portion 5 having an inner diameter of 280 mm and a length of 500 mm. Each compound roll was formed with four round calibers each having a semi-circular cross section having a radius of 11 mm.

Each compound roll was used as a finish roll for rolling a steel rod. As a result, 690 tons of steel per each caliber was rolled by the compound roll of Example 2, while only 210 tons of steel per each caliber was rolled by the compound roll of Comparative Example 2. This means that the compound roll of the present invention is more than three times as wear-resistant as the compound roll of Comparative Example 2 which was subjected to a HIP treatment at a temperature lower than the melting-start temperature of the alloy powder for the shell portion.

As described above in detail, since the shell portion of the compound roll of the present invention is prepared by a HIP treatment at a temperature equal to or higher than the melting-start temperature of the alloy powder, the shell portion has carbide particles having large particle sizes. Therefore, the wear resistance of the compound roll of the present invention is as high as three times or more that of the conventional compound roll.

Claims

1. A wear-resistant compound roll having a shell portion (4) produced by sintering an alloy powder consisting essentially, by weight, of 1.0-3.5 % of C, 2 % or less of Si, 2 % or less of Mn, 10 % or less of Cr, 3-15 % of W, 2-10 % of Mo, 1-15 % of V, and balance Fe and inevitable impurities, said shell portion containing carbide particles having particle sizes within the range of 3-50 µm in a martensite or bainite matrix.

2. The wear-resistant compound roll according to claim 1, further containing 3-15 % of Co.

3. The wear-resistant compound roll according to claim 1 or 2, wherein an area ratio of said carbide particles in the metal structure of the sintered shell portion (4) is 15 % or more.

4. The wear-resistant compound roll according to anyone of claims 1 to 3, wherein among said carbide particles having particle sizes of 0.5 µm or more, the number of carbon particles having particle sizes of 3 µm or more is 10 % or more.

5. A method of producing a wear-resistant compound roll comprising the steps of (a) charging an alloy powder (P) having a composition consisting essentially, by weight, of 1.0-3.5 % of C, 2 % or less of Si, 2 % or less of Mn, 10 % or less of Cr, 3-15 % of W, 2-10 % of Mo, 1-15 % of V, and balance Fe and inevitable impurities, into a metal capsule (2) disposed around a roll core portion (1); and (b) after evacuation and sealing, subjecting said alloy powder (P) to a HIP (hot isostatic pressing) treatment at a temperature equal to or higher than the temperature from which said alloy powder (P) starts to be melted.

6. The method of producing a wear-resistant compound roll according to claim 5, wherein said alloy powder (P) further contains 3-15 % of Co.

7. The method of producing a wear-resistant compound roll according to claim 5 or 6, wherein said HIP treatment is conducted at a temperature of 1100-1300 °C and at a pressure of 9.81 - 14.715 • 10^3 N/cm^2 (1000-1500 atm) in an inert gas atmosphere for 1-8 hours.

FIG. 1

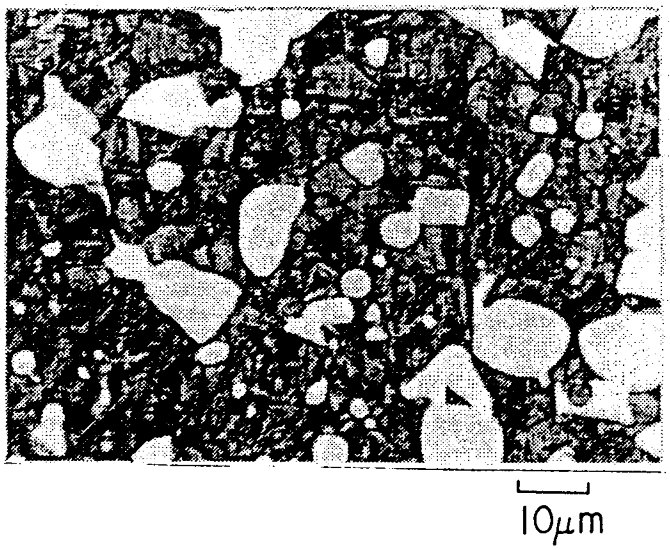

FIG. 2

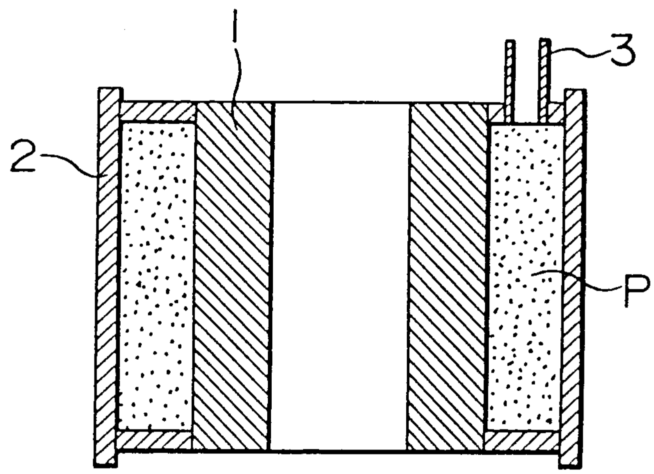

FIG. 3

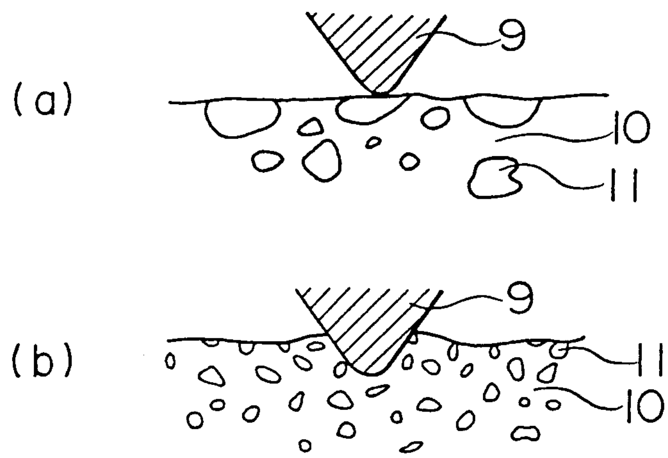
(a)
9
10
11
(b)
9
11
10

FIG. 4

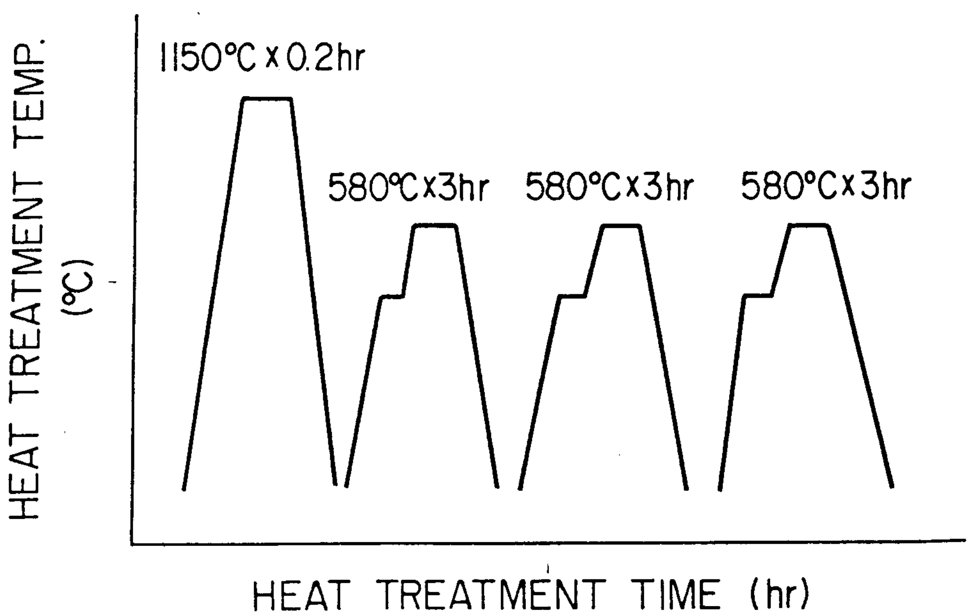
1150°C x 0.2hr
580°C x 3hr
580°C x 3hr
580°C x 3hr
HEAT TREATMENT TEMP. (°C)
HEAT TREATMENT TIME (hr)

FIG. 5

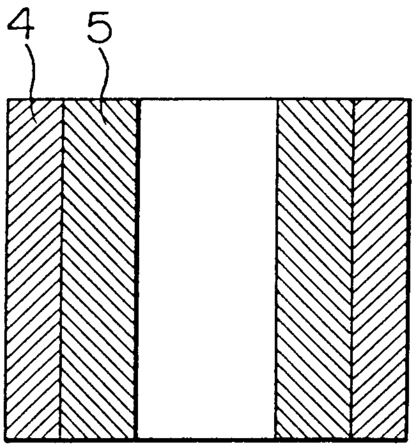

FIG. 6

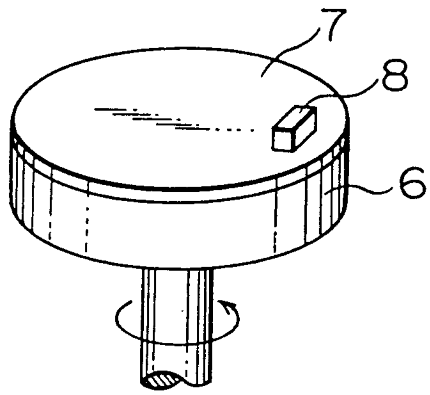

FIG. 7

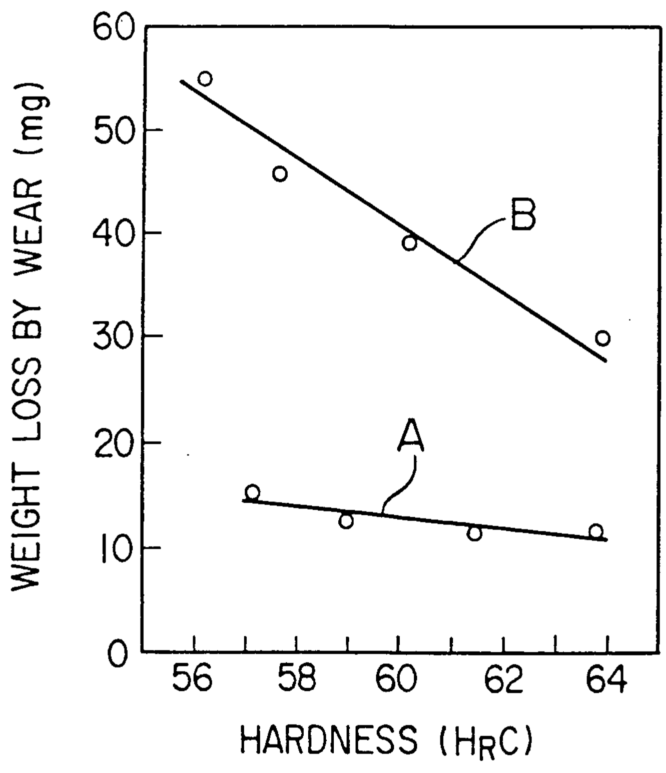

FIG. 8

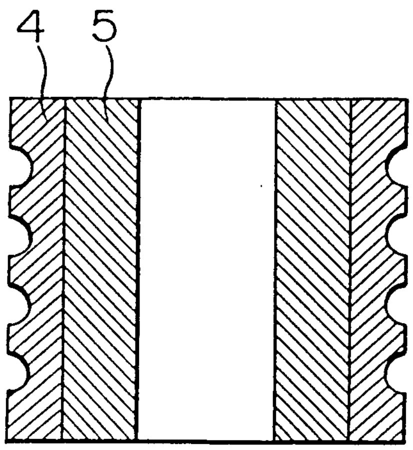

FIG. 9