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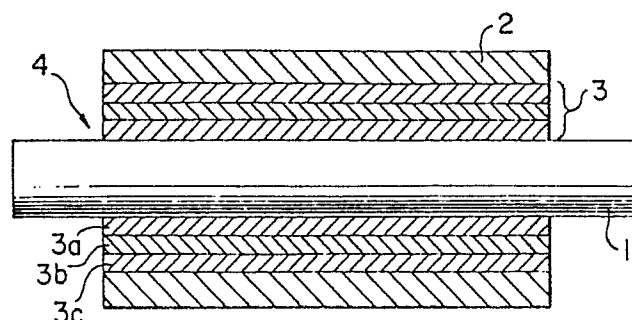
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(54) **Compound member and method for producing the same.**

(57) A compound member and a producing method thereof comprises a core (1) and a surface layer (2) formed by plasma spray deposition of powder material. At least one intermediate layer (3) is formed between the core and the surface layer. Difference in coefficient of linear thermal expansion between adjacent layers including the core and the surface layer is $3 \times 10^{-6}/^{\circ}\text{C}$ and below. The thickness of the intermediate layers (3) is 1.5 mm and over.

FIG. 1



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COMPOUND MEMBER AND METHOD FOR PRODUCING THE SAME

The present invention relates to a compound member comprising a core and a surface layer used for compound rolls, turbine rotors, various tools or the like and a method for producing the same.

There have been strong demands for recent Sendzimir rolls that should have a durability in high optical brightness. In order to meet these demands, it is necessary to provide finer or more homogeneous properties to a structure of the roll member. Also, 6-high mills or any other rolls may need a rolling operation under a high rolling reduction. There is a tendency that a diameter of rolls will be decreased. For that reason, it is necessary that the core of the roll should have a high mechanical strength and a high toughness and the surface layer of the roll should have spalling-proof and wear-proof. Also, a turbine rotor needs such demands for the properties. It is advantageous to use the compound member, comprising a core and a surface layer, for producing a compound roll or a turbine rotor that has such properties. There are the following methods for producing such a compound member:

Hot Isostatic Pressing Method;
Insert Metal Method;
Liquid Phase Sintering Method; and
Plasma Spray Deposition Method.

The hot isostatic pressing method is a method in which powders produced through a gas-atomizing method are arranged around the core, and are pressurized under a hot environment to form a compound member after the powders have been cold-molded. In the compound roll or turbine rotor produced by this method, since a thickness of a diffusion layer in an interface between the core and the surface layer is small, a stress concentration occurs during the heat treatment, disadvantageously, so that a crack or peel is likely to be occurred in the surface layer.

The insert metal method is a method in which a sleeve which has been made of powder material by sintering is shrink-fitted over a core to form a compound member. This method suffers from such a disadvantage that, when the operational loads imposed on the compound rolls or turbine rotors produced by this method is increased, the contact portion between the core and the sleeve would be peeled.

The liquid phase sintering method is a method in which a sleeve that has been made of powder material by sintering is diffused into a surface layer of a core to form a compound member. In the compound roll or turbine rotor formed by this method, a thickness of the diffused layer in the interface

portion between the sleeve and the core is small at about 2 mm. Therefore, this method suffers from a disadvantage that residual stresses would be concentrated on the interface portion resulting in occurrence of cracks or peels.

The plasma spray deposition method is a method in which powder material is deposited on a core surface by plasma spray to thereby form a compound member. The compound roll or turbine rotor produced by this method suffers from a disadvantage that a crack or a peel is likely to be occurred due to differences in coefficient of linear thermal expansion and elastic modulus between the core and the surface layer.

According to any one of the above-described method, the compound roll or turbine rotor suffers from the disadvantages that the stress concentration would occur in the vicinity of the interface between the core and the surface layer and that the surface layer would be peeled or cracked.

An object of the invention is to provide a compound member comprising a core and a surface layer of which mechanical properties are different from those of the core and a method for producing the same, which can eliminate any occurrence of stress concentration in an interface between the core and the surface layer and occurrence of peeling and crack of the surface layer, and which makes the mechanical properties of the surface layer be greatly different from those of the core and which is suitable for producing a compound roll for rolling and a turbine rotor.

Another object of the invention is to provide a compound roll of which surface layer is superior in spalling-proof and friction resistance, of which core has a high mechanical strength and a high stiffness, which is free from the crack and peeling of the surface layer and of which diameter can be reduced.

According to the present invention, a method for producing a compound member, including the step of forming a surface layer by a plasma spray deposition of powder material onto a core, is characterized by a step of forming at least one intermediate layer between the core and the surface layer by a plasma spray deposition so that a difference in coefficient of linear thermal expansion between the adjacent layers including the core and the surface layer is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below and a thickness of said at least one intermediate layer is 1.5 mm and over.

The compound member according to the invention is characterized in that at least one intermediate layer is formed between a core and a surface layer by a plasma spray deposition so that

a difference in coefficient of linear thermal expansion between the adjacent layers including the core and the surface layer is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below and a thickness of said at least one intermediate layer is 1.5 mm and over.

According to the present invention, a compound roll having a shaft portion made of a core having high mechanical strength and high toughness and a surface layer formed over the shaft portion and having wear-proof and spalling-proof is characterized in that at least one intermediate layer is formed between the shaft portion and the surface layer by a plasma spray deposition so that a difference in coefficient of linear thermal expansion between the adjacent layers including the shaft portion and the surface layer is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below, and a thickness of said at least one intermediate layer is 1.5 mm and over.

In one embodiment of the invention, the shaft portion is made of steel and the surface layer and the at least one intermediate layer are formed of powder material of hard metal by a plasma spray deposition over the shaft portion.

In another embodiment of the invention, the shaft portion is made of steel and the surface layer and the at least one intermediate layer are formed of powder material of ceramics by a plasma spray deposition over the shaft portion.

In the drawings:

Fig. 1 is a cross-sectional view of a compound roll according to the invention;

Fig. 2 is a schematic diagram showing an apparatus for producing the compound roll according to the invention;

Fig. 3 is a graph showing between the coefficient of linear thermal expansion and the crack occurrence state;

Fig. 4 is a graph showing a relationship between the thickness of the intermediate layer and the crack occurrence in the intermediate layer in the case where the core is made of steel and the intermediate layer is made of hard metal; and

Fig. 5 is a graph showing a relationship between the thickness of the intermediate layer and the crack occurrence in the intermediate layer in the case where the core is made of steel and the intermediate layer is made of ceramics.

A compound roll will now be described by way of example according to the present invention.

According to an embodiment of the invention, as shown in Fig. 1, the compound roll 4 has a shaft portion formed by a core 1 made of a steel with desired high mechanical strength and toughness. On a barrel portion of the shaft portion, an intermediate layer 3a is formed of which difference in the coefficient of linear thermal expansion to that of the core 1 is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below and a thickness is 1.5 mm and over. On an outer surface of

the intermediate layer 3a, another intermediate layer 3b is formed of which difference in the coefficient of linear thermal expansion to that of the intermediate layer 3a is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below and a thickness is 1.5 mm and over. Further, on an outer surface of the intermediate layer 3b, another intermediate layer 3c is formed of which difference in the coefficient of linear thermal expansion to that of the intermediate layer 3b is also $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below and a thickness is 1.5 mm and over. On an outer surface of the outermost intermediate layer 3c, a surface layer 2 having desired spalling-proof and wear-proof properties is formed. A difference in the coefficient of linear thermal expansion between the outermost intermediate layer 3c and the surface layer 2 is also $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below. The intermediate layers 3a, 3b, 3c, and the surface layer 2 are formed of powder material of hard metal by plasma spray deposition, thereafter sintered, subsequently hot forged and finally heat treated in a predetermined manner.

The plasma spray deposition of the powder material of hard metal is performed by an apparatus shown in Fig. 2. The apparatus includes a spray torch 5 with a spray nozzle 13, and powder material supply means 6 and 6' for supplying plural powder materials 8 and 8' to the spray torch 5. A controller 7 is connected to the spray torch 5 for controlling an operation of the torch 5 and for supplying working gas 10 and cooling water 11 to the spray torch 5. Reference numeral 12 denotes an electric supply source. Powder material supply gas 9 is supplied to the powder material supply means 6, 6' for supplying the powder materials 8, 8' to the torch 5.

In the apparatus, the powder materials 8, 8' are applied to the core 1 by the plasma spray deposition while rotating the core 1 in a direction indicated by an arrow a in Fig. 2, to thereby form the intermediate layer 3a. Subsequently, a mixture ratio or composition of the powder materials 8, 8' is changed so that the powder materials are applied to the intermediate layer 3a by the plasma spray deposition so as to form the intermediate layer 3b having a difference in coefficient of linear thermal expansion of $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below to that of the intermediate layer 3a. In the same manner, the intermediate layer 3c is formed on the intermediate layer 3b. The surface layer 2 having the desired mechanical properties is formed on the intermediate layer 3c by the plasma spray deposition.

In the foregoing embodiment, the powder material forming the intermediate layers and the surface layer is the powder material of hard metal but it is apparent that other powder materials such as ceramics and steel may be used.

Reasoning of the above-described numerical limitation to the coefficient of linear thermal expansion

sion and to the thickness of the plasma spray deposition layers will be explained with reference to Figs. 3 to 5.

The present inventors made various compound members having different coefficients of linear thermal expansion in the core and the plasma spray deposition layer in order to determine a suitable value of the coefficient of linear thermal expansion of the plasma spray deposition layers and inspect the state of occurrence of the cracks in the plasma spray deposition layers. The results are shown in Fig. 3. Fig. 3 shows the experimental results showing the relationship between the state of the crack occurrence in the plasma spray deposition layer and the coefficient of linear thermal expansion, the abscissa indicating the coefficient of linear thermal expansion of the plasma spray deposition layer and the ordinate indicating the coefficient of linear thermal expansion of the core.

As is apparent from Fig. 3, it will be understood that if the difference in coefficient of linear thermal expansion between the plasma spray deposition layer and the core is kept at $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below, the occurrence of crack may be suppressed.

It is known that, when two kinds of substances different in coefficient of linear thermal are bonded to each other and the thickness of one of the substances is very thin in comparison with the other substance, a maximum tensile stress is generated in the substance having the smaller coefficient of thermal expansion and a compression stress which is smaller than the maximum tensile stress is generated in the substance having the larger coefficient of thermal expansion. Also in the compound roll or turbine rotor, if the tensile stress generated in the plasma spray layers (intermediate layers) exceed the allowable stress level of the material forming the plasma spray deposition layer, cracks or peels occur in the plasma spray deposition layers. In order to determine the thicknesses of the plasma spray deposition layers, the present inventors have inspected the stress distribution within the compound member in the case where the core is made of steel and the plasma spray deposition layers are made of hard metal and ceramics. The experimental results are shown in Figs. 4 and 5 in which Δr is the thickness of the plasma spray deposition layers. As is apparent from Figs. 4 and 5, if the thickness of the plasma spray deposition layers is selected at 1.5 mm and over, the tensile stress generated in the plasma spray deposition layers does not exceed the allowable stress level of the material forming the plasma spray deposition layers. Therefore, if the thickness of the plasma spray deposition layers is selected at 1.5 mm and over, it is possible to prevent the occurrence of cracks or peels in the plasma spray

deposition layers.

In the foregoing embodiment, the number of the intermediate layers is three but it is possible to change the number of the intermediate layers in accordance with the magnitude of the difference in coefficient of linear thermal expansion between the core 1 and the surface layer 2. For instance, in the case where the difference in coefficient of linear thermal expansion between the core 1 and the surface layer 2 is at $6 \times 10^{-5} \text{ }^{\circ}\text{C}$, it is sufficient to provide a single intermediate layer having a coefficient of linear thermal expansion of $3 \times 10^{-5} \text{ }^{\circ}\text{C}$. In other words, it is sufficient that at least one intermediate layer is formed between the core and the surface layer by the plasma spray deposition so that the difference in coefficient of linear thermal expansion between the adjacent layers including the core and the outer surface is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below.

Although the above-described embodiment is related to the compound roll, the above-described numerical limitation in the thickness and the difference in coefficient of linear thermal expansion of the plasma spray deposition layer (intermediate layer) may be applied to a turbine roller or various tools.

Claims

1. A method for producing a compound member having a core (1) and a surface layer (2) of which mechanical properties are different from those of the core, including a step of forming said surface layer by plasma spray deposition of powder material onto said core characterized in that

said method includes

forming at least one intermediate layer (3) between said core (1) and surface layer (2) by the plasma spray deposition so that a difference in coefficient of linear thermal expansion between adjacent layers including said core and surface layer is $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below and a thickness of said at least one intermediate layer (3) is 1.5 mm and over.

2. A compound member having a core (1) and a surface layer (2) formed by plasma spray deposition characterized in that

at least one intermediate layer (3) is formed between said core and surface layer by plasma spray deposition, said at least one intermediate layer (3) having a coefficient of linear thermal expansion which makes differences in the coefficient of linear thermal expansion of adjacent layers including said core and surface layer be $3 \times 10^{-5} \text{ }^{\circ}\text{C}$ and below, and having a thickness of 1.5 mm and over.

3. A compound member as claimed in claim 2 characterized in that

said core (1) is made of steel and said at least one intermediate layer (3) and said surface layer (2) are made of powder material of hard metal.

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4. A compound member as claimed in claim 2 characterized in that

said core (1) is made of steel and said at least one intermediate layer (3) and said surface layer (2) are made of powder material of ceramics.

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5. A compound roll (4) for rolling comprising a shaft portion (1) formed by a core having high mechanical strength and high toughness and a surface layer (2) having wear-proof and spalling-proof characterized in that

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at least one intermediate layer (3) is formed between said shaft portion (1) and surface layer (2) by plasma spray deposition, said at least one intermediate layer (3) having a coefficient of linear thermal expansion which makes differences in the coefficient of linear thermal expansion of adjacent layers including said shaft portion and surface layer be $3 \times 10^{-5}/^{\circ}\text{C}$ and below, and having a thickness of 1.5 mm and over.

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6. A compound roll for rolling as claimed in claim 5 characterized in that

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said shaft portion (1) is steel and said surface layer (2) and said at least one intermediate layer (3) are layers which powder material of hard metal is spray deposited on said shaft portion by plasma spray deposition.

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7. A compound roll for rolling as claimed in claim 5 characterized in that

said shaft portion (1) is steel and said surface layer (2) and said at least one intermediate layer (3) are layers which powder material of ceramics is spray deposited on said shaft portion by plasma spray deposition.

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FIG. 1

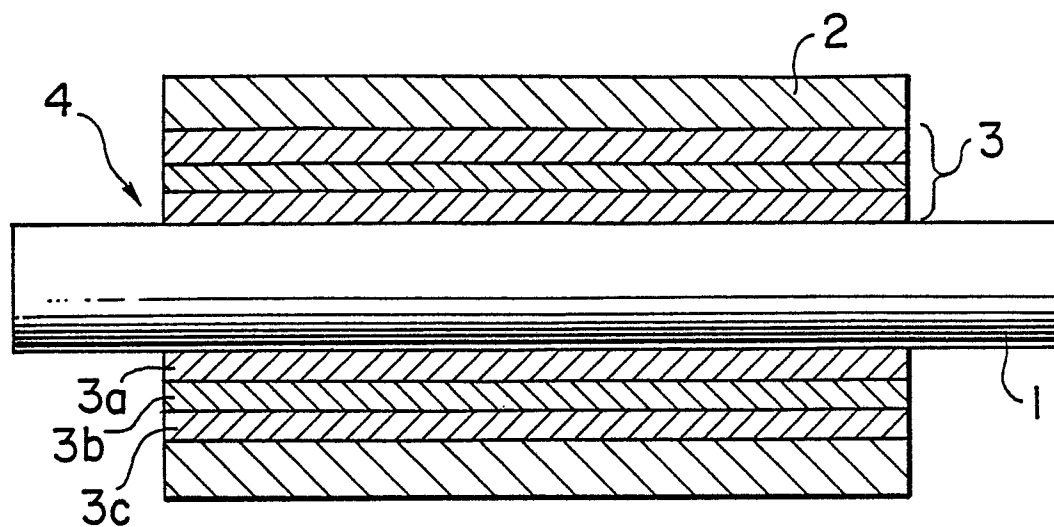


FIG. 2

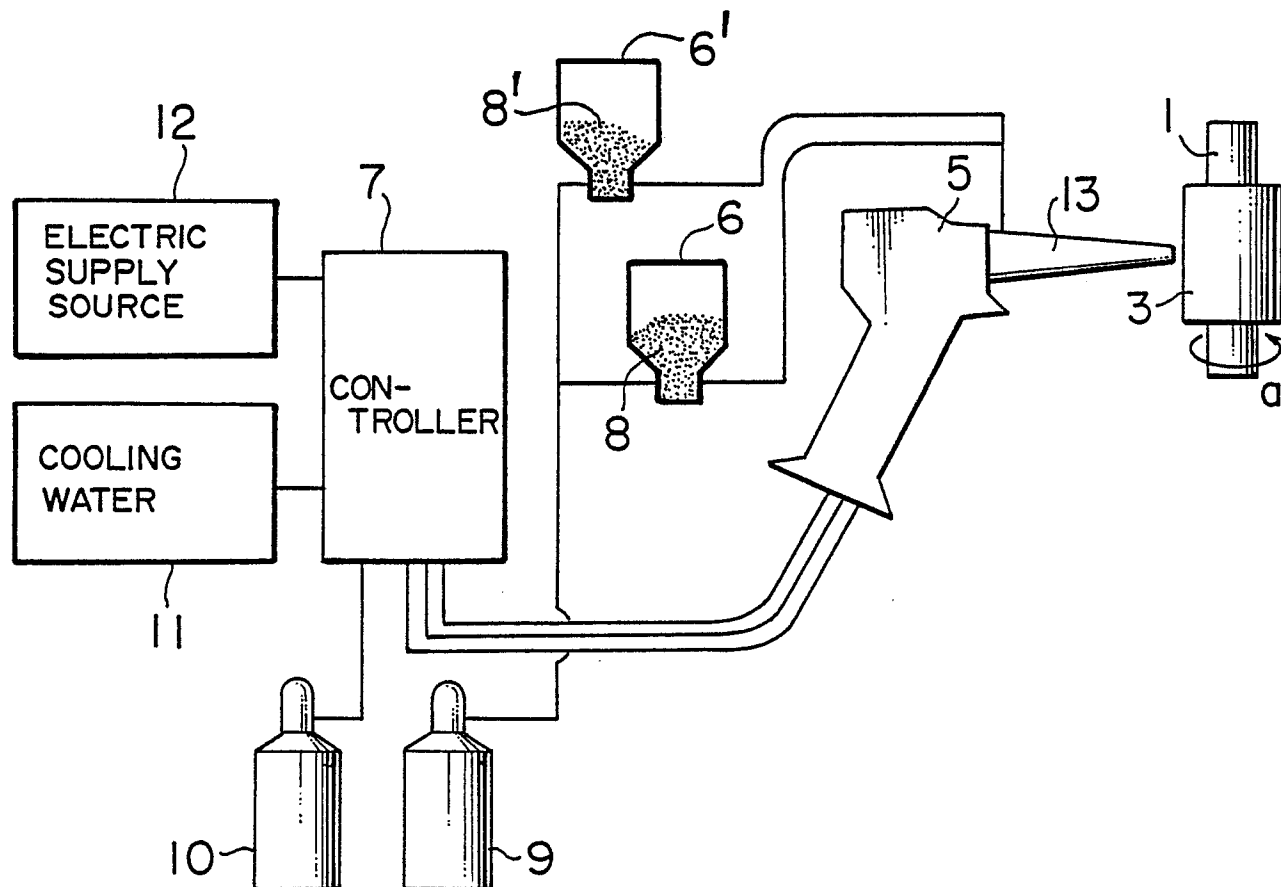


FIG. 3

