United States Patent [19]

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[11] **3,796,563**

[45] **Mar. 12, 1974**

[54] **METHOD OF MANUFACTURING METAL SHEET AND FOIL**

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[22] Filed: **May 24, 1972**

[21] Appl. No.: **256,276**

[52] **U.S. Cl.** **75/200,** 75/211, 75/214

[51] **Int. Cl.** **B22f 1/00,** B22f 3/18, B22f 3/24, B22f 3/00

[58] **Field of Search** 148/126; 75/211, 214, 200, 75/5

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[57] **ABSTRACT**

An aqueous slurry of superconcentrated iron ore powder and a binder is continuously deposited on a supporting carrier, dried, and the resultant coating heated in a reducing atmosphere to about 1,500° to 2,100° F. for several minutes to partially reduce the oxygen content of the ore. The coating is then stripped from the carrier and rolled to provide a strip of increased density. The strip is open coiled and heat treated to completely reduce the oxygen content of the ore, as well as to sinter the strip, and rolled to final gauge. The strip is then annealed, which both softens and further sinters the strip, and finish rolled.

5 Claims, No Drawings

METHOD OF MANUFACTURING METAL SHEET AND FOIL

BACKGROUND OF THE INVENTION

This invention relates to powder metallurgy, and more particularly to a method of producing metal strip and foil from an aqueous slurry of a powder of metal oxides and/or oxide ores.

It is broadly old to produce strips or foils of metal from metallic powders, e.g., iron powder. One well-known method for producing such strips may comprise, for example, preparing slurry of iron powder and a liquid binding and thickening agent and depositing the slurry on a supporting member. The resultant coating is dried and either sintered or removed from the supporting member and cold rolled into strip. Subsequently, the strip may be subjected to various combinations of heating and rolling operations.

While the above-described processing operations are satisfactory for producing strip from metals, such a process has not been successful for producing strip from metal oxides, oxide ores, and combinations thereof. It has been found that a dried slurry of metal oxides or oxide ores has insufficient strength to be removed from a supporting member and cold rolled, and sintering of the dried slurry prior to removal from the supporting member and rolling is not effective, since the particles of which the dried slurry is comprised will not satisfactorily cohere.

Thus, prior processes of producing sheet and foil from metal oxides or oxide ores, e.g., magnetite or hematite, comprised, for example, conventional processing comprising the production of pig iron in a blast furnace, the conversion of the iron into steel in an open hearth furnace and the mechanical reduction of ingots of said steel into slabs and hot-rolled strip. The hot-rolled strip was subsequently cold-rolled into sheet and foil. Alternatively, the magnetite or hematite could be crushed, beneficiated, pelletized, chemically reduced, and re-crushed to produce metal powder suitable for the above-described powder-processing steps.

It is an object of this invention to provide a method of producing sheet and foil from metal oxides and oxide ores, said method bypassing the above-described pyrometallurgical steps, e.g., in the case of magnetite or hematite, the steps of ironmaking and steelmaking, as well as the roughing and hot-rolling operations; it is also an object to bypass the pelletizing and re-crushing operations of the prior art powder metallurgy practice.

SUMMARY OF THE INVENTION

We have discovered that, when a slurry of a powder of a metal oxide or an oxide ore is prepared, and said slurry is deposited on a supporting member and given a relatively short, high temperature heat treatment in a reducing atmosphere until about 10 percent of the metal of the powder is in a pure metallic state, the resultant coating has sufficient strength so that it can be stripped from the supporting member and rolled into strip. Sufficient additional strength is developed during the rolling operation to permit the strip to be open coiled and heat treated in a reducing atmosphere wherein the oxygen content of the strip is substantially completely reduced. The strip is then rolled to substantially final gauge. It may then be annealed and finish rolled, e.g., skin passed.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The first step of the process of the invention is the preparation of a slurry of superconcentrated oxide ore and a thickening and binding means. Preferably, the slurry is aqueous, although organic liquid slurries, e.g., alcohols, could be used. While the invention is applicable to oxide ores such as copper ore, nickel ore and iron ore, as well as to metal oxides, e.g., iron oxide, provided that such ores and oxides are reducible by hydrogen, the preferred embodiment will be described in connection with a superconcentrated oxide ore of iron. By "superconcentrated oxide ore" is meant an oxide ore which is highly beneficiated whereby no more than about 2 percent of the ore, and preferably less than 1 percent thereof, is foreign matter. Such foreign matter includes, for example, silica.

The slurry is prepared by admixing a solution comprising about 70 percent by weight, of a powder of superconcentrated magnetite, hematite, or mixtures of magnetite and hematite, and about 30 percent, by weight, of an aqueous solution of a thickening and binding agent, e.g. a solution of ethyl or methyl cellulose. The powder, preferably, has a particle size of −100 mesh. The slurry is prepared so as to have an apparent viscosity of about 700 to 25,000 cps., and is deposited on a supporting carrier to provide a coating about 0.005 to 0.250 inch thick. The carrier may be, for example, an endless belt.

The endless belt, with the coating thereon, is transported into heating means, e.g., a furnace, where the coating is first dried and then heated in a reducing atmosphere to a temperature of about 1,500° to 2,100° F. for a period of time sufficient to reduce the oxygen content of the ore to a point where at least about 10 percent of the iron is in a metallic state. If the temperature of the furnace is about 1,800° F., this period of time may be from about a few seconds up to about 2 minutes, depending on the thickness of the coating. At lower temperatures this period is somewhat longer, depending upon the thickness of the coating, while at higher temperatures this period is correspondingly shorter.

It is essential for the powder to be reduced to a point where at least about 10 percent of the iron is in a metalllic state. At only very slightly lower percentages of metallic iron, the particles of the coating will not cohere satisfactorily and the coating will crumble when removed from the belt. At his point in the process, the iron ore cannot be substantially completely reduced, as unduly long times would be required.

In order to reduce the oxygen content of the iron ore sufficiently for 10 percent of the iron to be metallic, it is necessary to reduce the total oxygen content of the ore by 33 percent, if the ore is magnetite, and 40 percent if the ore is hematite. That is, the oxygen content of magnetite must be reduced from about 27 wt. percent to about 18.5 wt. percent, while the oxygen content of hematite must be reduced from about 30 wt. percent to about 18 wt. percent. For mixtures of magnetite and hematite, the required oxygen reduction is somewhere between 33 and 40 percent, depending upon the relative amounts of each ore.

It is important to note that these first four steps of the subject process, viz., preparing an iron ore slurry, depositing the slurry on a substrate, drying the slurry, and partially chemically reducing the ore, can be done continuously. This greatly enhances the commercial feasibility of the subject process.

The coating of partially reduced ore has sufficient strength so that it can be removed from the carrier. The coating is then hot or cold rolled to provide a strip of increased density. At this point in the process, the density of the strip is equal to 50 to 95 percent of the theoretical density of iron, i.e., 3.9 to 7.5 gm./cc.^{3}.

The strip is next open coiled and heated in a reducing atmosphere to reduce the oxygen content of the strip from about 18 wt. percent to a maximun of 2 wt. percent, and preferably to less than 0.2 wt. percent. A temperature within the range of 1,500°–2,100° F. for a time period of 4 to 6 hours is suitable, although longer times are of course permissible.

The strip is then hot or cold rolled to increase its density to the theoretical density of iron, viz. 7.9 gm./cc., and thus substantially eliminate porosity. The strip may be used in this condition. However, preferably its thickness is reduced to within about 2 percent of final gauge, and it is then annealed and finish rolled, e.g., skin passed.

As a specific example of our invention, a slurry of 70 wt. percent superconcentrated magnetite (containing 0.7 wt. percent gangue), 30 wt. percent of a 1 percent solution of Methocel 4,000, manufactured and sold by the Dow Chemical Company, which is a methyl cellulose solution having a viscosity of 4,000 cps., was prepared. The slurry was deposited on a stainless steel endless belt to provide a coating 0.060 inch thick and 4 inches wide. The coating was then transported through a heat treatment furnace containing a reducing atmosphere, e.g., hydrogen, at 1,800° F., where the coating was in the heating zone for about 2 minutes. It was then cooled, in a manner to prevent oxidation, to room temperature. It was 0.038 inches thick, and about 12 percent of the iron was in the metallic state.

The coating of partially reduced ore was then cold rolled into strip, thereby increasing its density to 6.0 gm./cc. and decreasing its thickness to 0.013 inch. The strip was open coiled and heat treated in a reducing atmosphere at 1,8000° F. for 16 hours to decrease the oxygen content of the strip to 0.1 wt. percent. The strip was then hot rolled to substantially final gauge of 0.007 inch. The hot rolling was done at 1,800° F. The density of the strip was 7.74 gm./cc. The hot-rolled strip was then annealed at 1300°–1400° F. and finish rolled. The strip was tested, and it was found to have a tensile strength of 32,900 psi. and a tensile elongation of 14.1 percent. Strip of similar compositions, but produced by the aforementioned prior art iron powder metallurgy techniques, had a tensile strength of 30,400 psi. and a tensile elongation of 13.5 percent. The strip is suitable for fabrication into metal containers or heat exchangers, for example.

While the subject process has been described in connection with unalloyed iron ore, it is permissible to add powders of alloying elements, e.g., carbon, to the ore.

We claim:

1. A method of producing a strip of metal from a powder of at least one member of the group consisting of metal oxides and oxide ores, said oxides and ores being reducible by hydrogen, comprising:

a. preparing a slurry comprising said powder and a thickening and binding means,

b. depositing said slurry on a supporting carrier to provide a coating,

c. drying said coating on said carrier,

d. heating said coating, while still on said carrier, in a reducing atmosphere at a temperature and for a time sufficient to partially reduce the oxygen content of said powder whereby at least about 10 percent of the metal of the powder is in a metallic state, the balance of said metal being combined as one or more oxides, as well as to cause the particles of said coating to cohere,

e. removing the coating from the carrier to provide a formed layer,

f. rolling said formed layer into a strip having a density of about 50 to 95 percent that of the theoretical density of the metal,

g. open coiling the strip and heating it in a reducing atmosphere for a time sufficient to reduce the oxygen content of the strip to about 2 wt. percent max., and

h. rolling the strip to increase its density to substantially said theoretical density.

2. A method as recited in claim **1,** in which said slurry is aqueous.

3. A method of producing a strip of ferrous metal from a powder of iron ore, comprising:

a. preparing a slurry comprising said powder and a thickening and binding means,

b. depositing said slurry on a supporting carrier to provide a coating,

c. drying said coating on said carrier,

d. heating said coating, while still on said carrier, in a reducing atmosphere to a temperature within the range of 1,500° to 2,100° F. for a period of time sufficient to partially reduce the oxygen content of said ore whereby at least about 10 percent of the iron is in a metallic state, the balance of said iron being combined as one or more oxides, as well as to cause the particles of said coating to cohere,

e. removing the coating from the carrier to provide a formed layer,

f. rolling said formed layer into a strip having a density of 3.8 to 7.3 gm./cc.,

g. open coiling the strip and heating it in a reducing atmosphere for a time sufficient to reduce the oxygen content of the strip to about 2 wt. percent max., and

h. rolling the strip to increase its density to about 7.7 gm./cc.

4. A method as recited in claim **3,** in which:

1. said slurry comprises 60 to 80 wt. percent of said powder, balance water and a thickening and binding means,

2. in step (g), said strip is heated to 1,500° to 2,100° F. for 4 to 6 hours, and

3. the method includes the additional step of annealing.

5. A method as recited in claim **4,** in which said iron ore is superconcentrated.

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