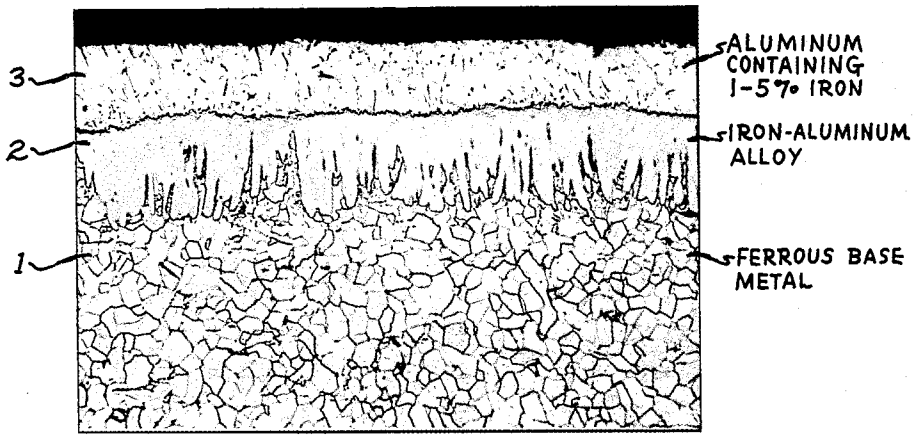
Oct. 16, 1962 E. J. METS 3,058,206

ALUMINUM COATING OF FERROUS METAL AND RESULTING PRODUCT

Filed Dec. 27, 1956



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United States Patent Office 3,058,206 Patented Oct. 16, 1962

3,058,206
ALUMINUM COATING OF FERROUS METAL AND RESULTING PRODUCT

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Filed Dec. 27, 1956, Ser. No. 630,831
10 Claims. (Cl. 29—196.2)

The present invention relates to coating of ferrous metal articles, and more particularly to a process of aluminum coating ferrous articles which results in improved corrosion resistance of the coated articles.

The advantages of a protective aluminum coating for ferrous articles are well known in the art, including, for example, such benefits as good adherence to the base metal, permanence in air due to formation of an inert oxide film, light weight, ductility, hardness and other desirable characteristics. However, while ferrous articles treated with known aluminum coating processes may have, in general, satisfactory corrosion resistance properties under ordinary atmospheric conditions, it has been observed that known types of aluminum coated articles under prolonged exposure to sulfur-bearing atmospheres such as found in industrial areas or to salt-containing air such as prevalent in marine or coastal regions exhibit marked corrosion effects which lead to ultimate deterioration of the ferrous article.

It is an object of the present invention to provide aluminum-coated ferrous base materials and articles having improved corrosion resistance, particularly under prolonged exposure to severely corrosive atmospheres.

It is another object of the invention to provide an improved process of producing a protective aluminum coating on ferrous articles which confers increased corrosion resistance to the ferrous articles.

It is a further object of the invention to provide on ferrous base metal an aluminum coating which not only inherently is corrosion resistant but also serves to minimize the electrochemical differences in the coating structure which would otherwise lead to corrosion effects.

The improved corrosion resistant ferrous product is produced, in accordance with the invention, by immersing the ferrous article in a bath of molten aluminum to which has been added a minor but effective amount of iron. It has been found that such addition of iron to the aluminum dipping bath markedly improves the protection afforded by the aluminum to the ferrous base material against corrosive agents, and particularly weathering effects in corrosive industrial atmospheres.

The invention will be better understood from the following description taken in conjunction with the accompanying drawing in which the single FIGURE is a photomicrograph showing a cross section of a ferrous article coated in accordance with the present invention.

Various methods have been used in the past for aluminizing ferrous materials, and of these the so-called hot-dip process, wherein the ferrous article is immersed in a molten aluminum bath, has been found quite practical and has been extensively used in industry. In this process, when the article comes into contact with the molten aluminum in the bath, an alloy bonding layer composed of iron-aluminum compounds is formed at the surface of the ferrous article. This continuous alloy layer is formed by diffusion of the molten aluminum into the base iron producing compounds of definite chemical composition. These compounds generally have a high iron content of the order of 60–70%, and while they do exhibit resistance to corrosion by high temperature oxidation, they show only slight resistance to corrosion under normal atmospheric conditions. In the usual hot-dip process, however, there is additionally formed overlying the bonding alloy layer a distinct outer layer which has

a composition corresponding to that of the aluminum bath. Since heretofore in the art reliance has been placed on the outer aluminum layer for effective corrosion resistance, it has been the practice to use a coating bath of commercially pure aluminum to form a pure aluminum outer layer overlying the intermediate (interfacial) alloy layer.

It has been found, in accordance with the invention, that by adding iron in the small amounts hereinafter specified to the molten aluminum bath, there is provided an outer layer of aluminum which contains the corresponding amount of iron, and which considerably improves the corrosion resistance of the coated ferrous article over that afforded by the relatively pure aluminum coatings heretofore used.

Shown in the drawing is a photomicrograph at 250× magnification of a cross section of a ferrous body treated in a hot-dip process in accordance with the invention wherein the iron body was introduced into a molten aluminum bath of commercially pure aluminum to which 1–5% iron by weight had been added. As illustrated, the coated structure comprises the iron base material 1, an interfacial bonding layer 2 of iron-aluminum alloy compounds, and an outer layer 3 of an aluminum alloy containing 1–5% iron.

As will be observed, the hot-dip coating process by which the illustrated structure was formed results in a composite coating comprising bonding layer 2 and outer aluminum alloy layer 3, each of which constitutes a distinct homogeneous continuous coating overlying the base ferrous metal. In articles coated in the prior hot-dip aluminizing processes, reliance was placed principally on the thickness and density of these outer and intermediate layers to provide the necessary protection against corrosion of the underlying base metal. The thicker these coatings, the longer was the period of time required before external corrosive agents could penetrate the layers to the base ferrous metal. However, the ductility of the coatings decreased with increased thickness and the necessity for maintaining sufficient ductility to withstand the bending and forming operations to which the ferrous articles were subjected limited in practice the thickness of the outer and intermediate layers. By virtue of the provision of the outer aluminum-iron alloy layer in accordance with the present invention, improved corrosion resistance can be obtained without the necessity for an excessively thick coating and without thereby sacrificing desirable ductility in the coated product.

In a series of comparative tests made in connection with the present development, a set of test panels of low carbon steel were coated in aluminum coating baths containing, respectively, varying concentrations of Fe, Si, Zn and Ni. The steel panels thus coated were subjected to accelerated corrosion tests comprising a standard salt fog exposure test (ASTM Spec. B117–54T) and sulfur-bearing conditions simulating heavy industrial atmospheres. As a result of these exposure tests, it was found that the test panels coated in aluminum baths containing Zn, Si, and Ni, and which varied in concentrations of those elements from 1–10%, showed considerably poorer corrosion resistance than panels coated with commercially pure aluminum.

On the other hand, those samples coated from aluminum baths containing iron within the limited range of about 1–5% showed significant improvement in corrosion resistance in these tests. For example, after more than 2,000 hours in the salt fog exposure test, panels coated with commercially pure aluminum (containing .45% Fe) showed characteristic black etching and scattered red rust on 35% of their surface, whereas panels coated with aluminum containing about 3.5% Fe showed no significant attack on the coating. In the same test, the panels

having 1.8% Fe in the aluminum coating showed etched black areas on about 20% of the surface, but no red rusting, panels with 2.6% Fe had light scattered grey areas on about 10% of the surface, and panels with 5.3% Fe (removed after 921 hours' exposure) exhibited an etched black attack on 80% of their surface accompanied by red rusting.

Analogous results were obtained in the sulfur exposure test, wherein after 123 days' exposure characteristic black spotting and red rust pitting effects were observed over the entire surface of panels coated with commercially pure aluminum and those coated with aluminum containing over 5% Fe. Least amounts of these corrosion effects were observed in the panels coated with 1.8% Fe, 2.6% Fe and 3.5% Fe, with no red resting and only a few scattered black spots being present in the 3.5% Fe coating.

The results of these and other tests appeared to demonstrate than an amount of iron in the aluminum bath ranging from 1–5%, and preferably about 3–4%, served to markedly improve the corrosion resistance of the aluminized articles under severe atmospheric conditions.

While it is not fully clear what produces this substantial improvement, some explanation may be found in fact that incorporating iron in the outer exposed layer reduces the electrochemical potential between the outer layer and the intermeditae bonding layer which consists principally of $FeAl_3$ compounds. This effect appears to be demonstrated in a test similar to those above using copper alloy nuts and bolts to connect the aluminized panels, wherein less galvanic attack of the coating was noted with the higher iron content panels than with those of lower iron content. So far as can be determined, there is no effect produced by the iron addition on the Fe–Al compound intermediate layer. The increase in iron content apparently makes the outer layer more compatible with the intermediate layer and the base iron, resulting in a much slower rate of corrosion attack by galvanic action of the coating as a whole. The improved effect does not appear to be influenced by bath temperature or immersion time, but is dependent only on the composition of the outer layer.

The role of the iron in the outer layer in producing improved corrosion resistance in accordance with the invention is unexpected, in that the prior art has heretofore considered the presence of as much as 1% iron in aluminum to be detrimental to corrosion resistance, and efforts have generally been made in the past for that reason to use as pure aluminum as possible in the coating bath. For this reason also, it has been the practice heretofore to avoid prolonged use of the coating bath, which after repeated dipping of ferrous articles tended to have a higher iron content. The present discovery, therefore, is of advantage in that longer aluminizing operations can now be carried on before the bath must be scrapped due to excessive iron content. It further appears that addition of iron in the stated concentration tends to retard further solution of iron from the base material into the bath.

It is important to note in this connection that merely immersing the ferrous part for a longer period in the aluminum bath or raising the temperature of the bath, while effecting increased removal of iron from the article, does not appreciably change the aluminum bath composition, since such steps merely serve to produce thicker intermediate alloy layers which utilize the additional iron removed from the base material. The distinct outer aluminum layer formed by the hot-dip process appears to be constituted solely by the molten bath material clinging to the part as it is removed from the bath, and in accordance with the invention the composition of this outer aluminum layer is modified by the addition of iron to the aluminum bath independently of any iron removed from the base material during the dipping process.

A typical process which may be used in practicing the invention is as follows, it being understood that the particular procedure set forth is merely illustrative and in no way limits the scope of the invention:

The ferrous article to be aluminized is initially vapor degreased and then pickled in hot acid. After being rinsed in cold water, the part is completely dried. The thus cleaned and dried part is then immersed in a molten aluminum bath containing about 3% by weight of iron, the temperature of the bath being 700–800° C. and the immersion period ranging from 30 seconds to about 4 minutes depending on the size of the articles. The part is then removed from the bath and the coating thereon is allowed to solidify. After solidification of the coating the coated part is water quenched or air cooled.

The iron added to the molten aluminum bath may be in the form of soft iron wire which dissolves in the bath, but it will be understood that the particular form of the iron added or the manner of addition is not critical to the invention.

The thickness of the intermediate alloy layer **2** is preferably about 2–3 mils, but as previously indicated the thickness can be controlled as desired merely by varying the time of immersion and/or temperature of the bath. The thickness of the outer layer **3** in a typically coated part is about 2 mils, and this can be controlled to a practical extent by variations in the viscosity of the aluminum bath.

Addition to the aluminum bath of amounts of iron after reaching the maximum 5% specified in accordance with the invention appears to cause a rather abrupt decrease in corrosion resistance afforded by the outer layer, whereas the addition of less than 1% iron produces very little improvement in resistance to the galvanic corrosion effects characteristic of the prior types of aluminized parts coated with commercially pure aluminum.

In addition to the previously mentioned advantages of the present invention with respect to improved resistance to severely corrosive atmospheres, and the longer use of aluminum dipping baths which it permits, there is afforded wider latitude and greater economy in the type of starting aluminum ingot material which may be used for coating purposes, since the cheaper grades of aluminum with iron content greater than the .25–.5% requirements for commercially pure aluminum and within the 1–5% range of the present invention can be employed for aluminizing operations.

While the present invention has been described with reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the scope of the invention. Therefore, the appended claims are intended to cover all such equivalent variations as come within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. The method of coating a ferrous metal body which comprises introducing the ferrous metal body into a molten aluminum bath having about 1–5% iron incorporated therein, and removing the ferrous metal body from the bath.

2. The method of coating a ferrous metal body which comprises applying thereto molten metal coating material consisting essentially of aluminum and about 1–5% iron.

3. In the method of hot-dip coating of ferrous base metal with aluminum, the step comprising adding about 3–4% iron to the molten aluminum bath before dipping the ferrous base metal therein.

4. A corrosion resistant product comprising a ferrous metal base, an intermediate layer of iron-aluminum alloy overlying said ferrous metal base, and an outer layer composed of an alloy of aluminum and about 1–5% iron overlying said intermediate iron-aluminum alloy layer.

5. A ferrous product having high resistance to corrosion in severely corrosive atmospheres comprising a ferrous metal base, and a composite protective coating overlying the ferrous metal base, said composite protective coating comprising an inner layer of iron-aluminum alloy

compounds and an outer layer composed of an alloy of aluminum and about 3–4% iron.

6. A corrosion resistant product comprising a ferrous metal base, an intermediate layer of iron-aluminum alloy overlying said ferrous metal base and having a thickness of about 2 to 3 mills, and an outer layer about 2 mils thick composed of an alloy of aluminum and about 1–5% iron overlying said intermediate iron-aluminum alloy layer and bonded thereby to said ferrous metal base.

7. A corrosion resistant product comprising a ferrous metal base, an intermediate layer of iron-aluminum alloy having about 60–70% iron overlying said ferrous metal base and having a thickness of about 2 to 3 mils, and an outer layer about 2 mils thick composed of an alloy of aluminum and about 1–5% iron overlying said intermediate iron-aluminum alloy layer and bonded thereby to said ferrous metal base.

8. A corrosion resistant product produced by introducing a ferrous metal body into a molten aluminum bath having about 1–5% iron incorporated therein, and removing the ferrous metal body from the bath.

9. The method of coating a ferrous metal body which comprises providing a molten bath composed of molten aluminum having about 1–5% iron incorporated therein, introducing a ferrous metal body into said molten bath, and removing the ferrous metal body from the bath.

10. The method of coating a ferrous metal body which comprises adding about 1–5% iron to a molten aluminum bath, introducing a ferrous metal body into the thus provided molten bath, and removing the ferrous metal body from the bath.

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