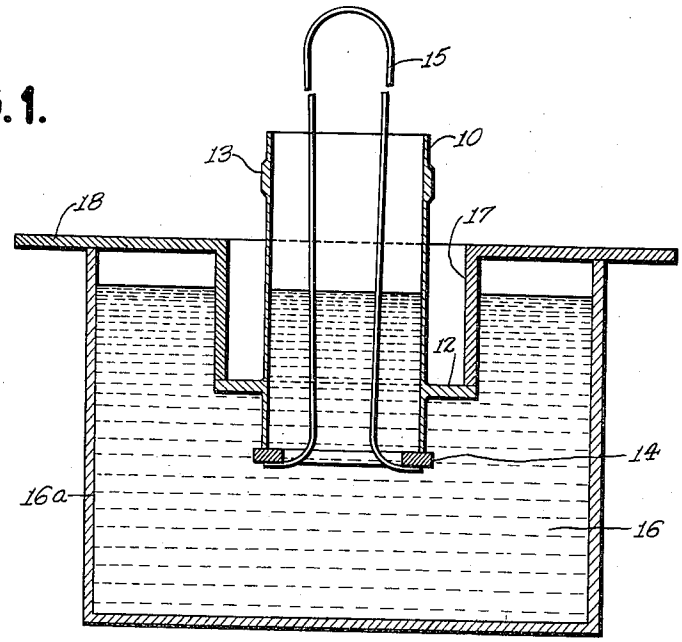
March 19, 1946. M. G. WHITFIELD ET AL 2,396,730

COATING METALS

Filed Oct. 24, 1941 2 Sheets-Sheet 1

FIG. 1.



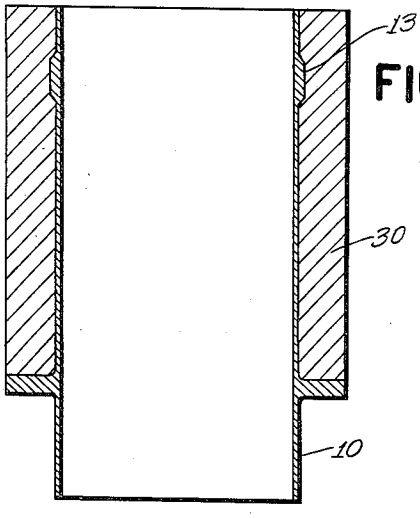


FIG. 4.

FIG. 5.

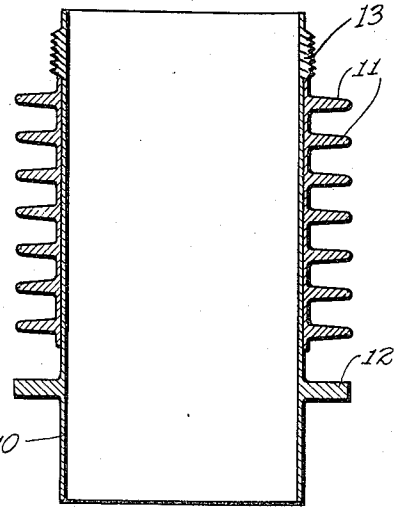
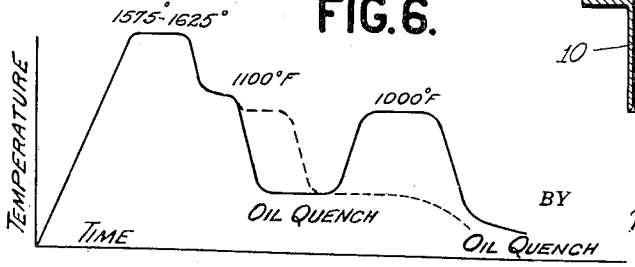


FIG. 6.



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COATING METALS

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FIG. 2.

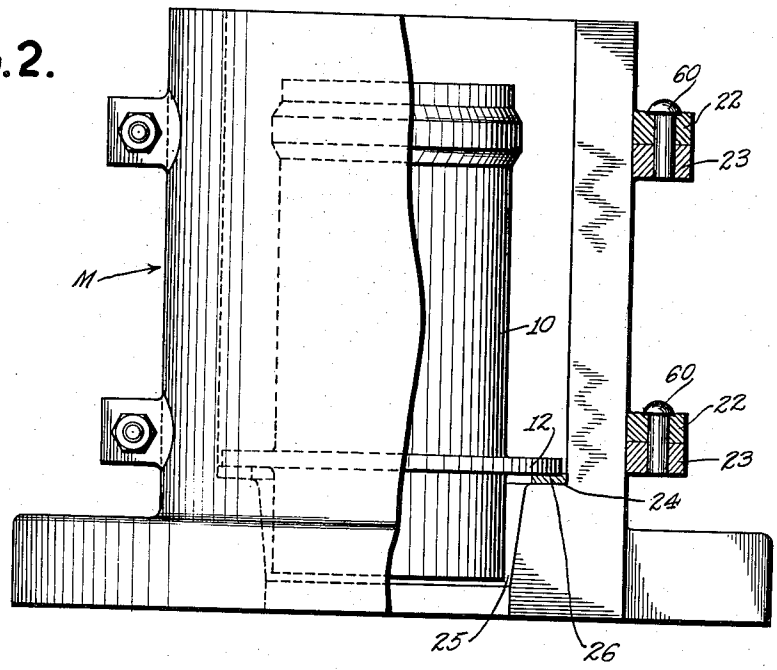
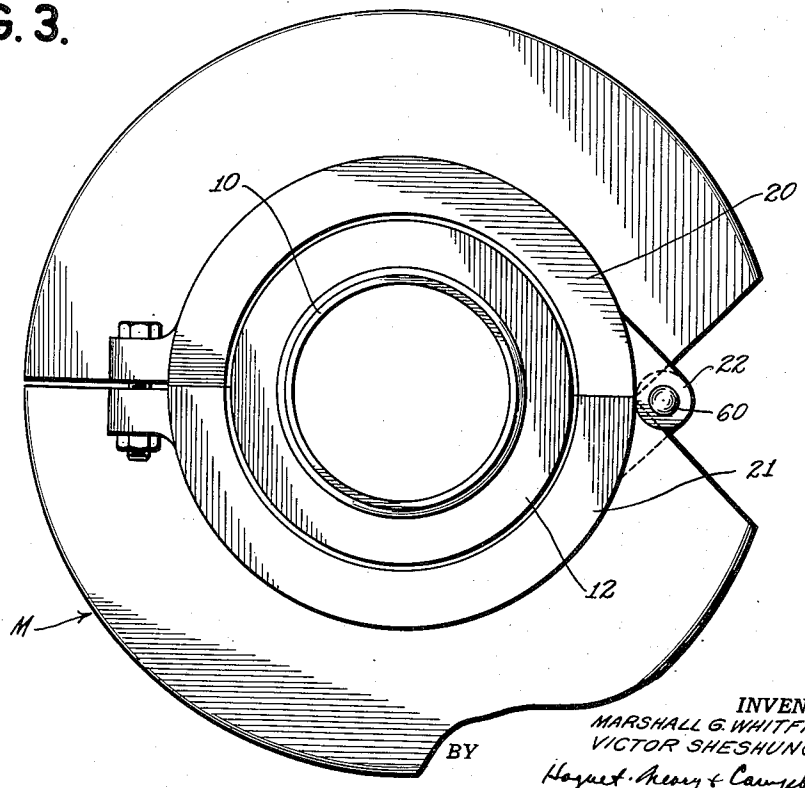


FIG. 3.



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UNITED STATES PATENT OFFICE

2,396,730

COATING METAL

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Application October 24, 1941, Serial No. 416,328

7 Claims. (Cl. 22—204)

This invention relates to the coating of metals with other metals, and has particular reference to the coating of ferrous metals with aluminum or its alloys.

Heretofore various methods have been proposed for coating ferrous metals with aluminum with a view to procuring a composite structure which would withstand mechanical deformation, wide variation temperature, and the like, without separation at the zone between the two metals. These methods involved dipping the ferrous metal in molten aluminum, casting the aluminum on the ferrous metal, or spraying the ferrous metal with molten aluminum with or without the use of fluxing or bonding materials. Few of these methods have been sufficiently satisfactory to justify their commercial use for all purposes. Also, these prior methods were complicated and expensive and the results of their use were so variable that production of uniform products was not at all certain.

In accordance with the present invention, a process is provided for applying a coating of aluminum, or aluminum base alloys, and other non-ferrous metals having similar characteristics, to a base metal, such as one of the iron or steel metals, to any desired degree of thickness while at the same time producing a bond between these metals which will withstand deformation, wide temperature changes and other rigorous treatment.

Also in accordance with the present invention, particularly when applied to the coating of steel, the process may be utilized to heat-treat the steel to temper and harden it without the use of any other steps than those normally involved in the coating operation.

The preferred process of the invention is conducted essentially in four steps, beginning with a thorough cleaning of the base metal of all foreign matter, as by brushing or sand-blasting, to remove scale, dirt, and other material which would interfere with the formation of a strong bond. A chemically clean surface is not required; it is necessary merely to clean the surface sufficiently to remove scale, dirt and grease therefrom.

If only part of the ferrous article is to be coated, the portions not to be coated are covered with a suitable stop-off preparation which will prevent contact between those portions and the aluminum, or aluminum base alloy, and the article is then immersed in a bath of molten aluminum, or aluminum base alloys, for a sufficient time and at a proper temperature to cause the aluminum to alloy with the ferrous metal and form a thin iron-aluminum alloy bond on the surface of the article. Preferably this operation is of short duration in order to preclude deep alloying action on the surface of the article, inasmuch as the iron-aluminum alloy formed thereupon is a hard, brittle metal which is not capable of withstanding considerable shock or distortion, and hence should not be so thick as to weaken the eventual bond.

A third step of the process consists of immediately transferring the article coated with the thin film of molten aluminum, to a second bath for applying a second film to the article. This second bath preferably has a lower melting point than aluminum or aluminum alloy of the first bath, and is maintained at a temperature below the criitcal temperature of the article, thereby also serving as a quenching medium for hardening and toughening the metal, but not so low as to cause the initial aluminum coating to freeze to any substantial degree. An alloy of aluminum and a temperature-depressing metal or metals has proven effective for that purpose. The article is retained in the quenching bath until its temperature has attained substantially the temperature of the quenching bath, and then a layer of aluminum of any desirable thickness, is applied over the wetted surface remaining after removal from the quenching bath. This aluminum layer may be any desired thickness, and is preferably applied by casting it on the article, preferably by placing a mold about the wetted surface of the article and pouring molten aluminum in contact therewith to the desired depth or thickness. When the aluminum solidifies, a substantially homogeneous layer of aluminum is provided on the surface of the article which is secured by the bond of ferro-aluminum alloy to the ferrous article. This layer of aluminum may then be machined or otherwise treated to produce the finished or semi-finished product desired.

As an example of one use of the method of this invention, an internal combustion engine cylinder, including barrel and head as a unit, or barrel and head separately, may be provided on its outer surface with a muff of aluminum in the manner described and the muff provided with grooves or slots forming cooling fins, these grooves or slots either being formed by casting when the aluminum is applied to the cylinder, or by machining the aluminum muff so formed, as by saw-cutting or milling grooves in the metal. Cylinder barrels formed of appropriate types of steel and treated in accordance with the process outlined above are characterized by a high Rockwell hardness,

toughness, and by a firmly seated and chemically-bound cooling structure affixed thereto.

It will be seen that the method of the present invention provides a very simple, inexpensive and efficient method for applying to a ferrous base metal article a layer or plate of aluminum, or an alloy thereof, to any desired thickness which may be used for the purpose of providing the base metal with added properties or facilities, such as, for example, the rapid cooling afforded by the aluminum because of its higher heat conductivity.

For better understanding of the invention, reference may be had to the accompanying drawings, in which:

Figure 1 is a view in vertical section illustrating the manner in which a cylinder barrel may be coated by dipping the same in a bath of molten aluminum;

Figure 2 is a view in vertical section of a typical form of mold for casting aluminum about the cylinder barrel;

Fig. 3 is a plan view of the mold of Fig. 2;

Fig. 4 is a view in vertical section of a cylinder barrel with the aluminum muff applied thereto;

Fig. 5 is a view in vertical section of the cylinder barrel with the muff treated to provide cooling fins; and

Fig. 6 are diagrammatic showings of typical heat treating operations in accordance with the present invention.

In accordance with the present invention and as illustrative of the method of practicing the invention, a cylinder barrel 10 for an airplane engine is treated to produce a finished construction having cooling fins 11 thereon, as shown particularly in Fig. 5 of the drawings. The particular cylinder barrel 10, shown by way of example, may consist of a tubular member of any desired dimensions having a radially directed flange 12 thereon and a suitably raised annular ring 13. No special surface finish, such as roughening, need be provided to aid in securing the adhesion or binding of the aluminum thereto.

Various types of steel may be used in the preparation of such cylinder barrels, typical of which is high strength SAE 4140 steel (a chrome-molybdenum steel, containing 0.8–1.1% chromium, 0.15–0.25% molybdenum, 0.35–0.45% carbon, 0.60–0.90% manganese, and not more than 0.04–0.05% phosphorous and silicon each).

Inasmuch as it is desired to coat only a portion of the exterior of the barrel 10, namely, that portion above the flange 12, the remainder of the barrel, including the inside and the flanges, may be coated with a "stop-off" preparation, such as, for example, a lime solution or equivalent coating. The barrel is then supported on a ring 14 which may be formed of steel, iron, or other material capable of withstanding the high temperature of the coating bath and which is provided with a handle 15 by means of which the cylinder 10 may be lowered into bath 16. The bath 16 which may be an externally heated crucible 16a, or the like, is partially filled with molten aluminum, or an aluminum base alloy, and maintained at a temperature between about 1525 and 1625° F. The temperature of the bath 16 depends upon the melting point of the aluminum-containing metal of which it is composed, but in any case its temperature is maintained somewhat above its melting point, as indicated.

An annular collar or sleeve 17 is supported loosely on the upper surface of the flange 12 of the cylinder barrel and is lowered into the molten aluminum with the cylinder barrel 10. The collar 17 is provided with outwardly projecting arms 18 which engage the top edge of the crucible 16a so that as the cylinder barrel 10 is lowered into the bath the collar 17 will be stopped by engagement of arms 18 with the top edge of the crucible 16a. The descending barrel 10 thus drops below the collar 17 and allows the molten aluminum to flow between its lower edge and the flange 12 on the cylinder barrel.

The function of the ring 14 and the collar 17 is to part and push aside and thus prevent contact of the slag or aluminum oxide on the top of the bath with the portions of the cylinder barrel 10 to be coated. Thus, as the cylinder barrel 10 and the ring 15 are lowered into the bath 16 the aluminum oxide will be parted and will flow around the cylinder barrel and upwardly around the collar 17. When the collar 17 and the flange 12 separate, the molten metal beneath the oxide scum flows around the upper portion of the cylinder barrel and comes into intimate contact with it.

Temperatures between about 1525° and 1625° F. are used to promote a very quick formation of a ferro-aluminum alloy at the engaging surfaces of the bath 16 and the cylinder barrel 10. A sufficient bond between the aluminum and the cylinder barrel 10 will be obtained within one to six minutes, or in the case of small articles, such as, for example, wire, within a few seconds. Inasmuch as only a thin layer of the ferro-aluminum alloy is desirable in most instances, the formation of the alloy is arrested by cooling the coated barrel 10. This may be accomplished by immersing it in a second bath of molten aluminum or an aluminum base alloy, at about the melting point of alumium or slightly below, preferably between 1000° and 1250° F. Preferably a bath containing aluminum and silicon is used, with the silicon depressing the melting point of the aluminum. For example, a suitable bath may contain about 13% silicon. The use of such an alloy bath also has the added advantage of cleaning the surface of the aluminum coating on the cylinder barrel. It appears that when the highly heated barrel is immersed in the lower temperature bath, the heat of the barrel raises the temperature of the bath adjacent the barrel surface and the consequent increased fluidity of the bath washes or strips the oxide from the surface of the aluminum coating. The second bath thus arrests the alloying action and also places the surface of the barrel in condition for the subsequent coating operation. The reduced temperature of the barrel also facilitates the subsequent coating operation because the coating temperature is more nearly equaled.

During the initial coating operation in bath 16, the cylinder barrel 10 is heated to a high temperature, such that solution of the constituents of the steel takes place, thus placing the entire barrel in a condition to be hardened by subsequent quenching.

Inasmuch as it is known that many steels, when allowed to cool in air or quenched in oil from temperatures on the order of 1525° F. will form an extremely hard but brittle martensitic crystalline structure in the metal, advantage is taken of the use of the second bath to quench the steel rapidly to a temperature below the critical, i. e. below the beginning of precipitation of ferrite from the austenite on cooling. By regulating the subsequent treatment of the steel, the desired properties are obtained. This quenching opera-

tion results from the immersion of the barrel in the second bath of aluminum or an aluminum base alloy maintained at a temperature below the critical temperature of the steel involved, but preferably above martensite formation temperature.

A bath of this type has several exceedingly valuable advantages, namely, (1) a rapid quench which results from the especially good heat conductivity of the molten aluminum or aluminum base alloy, of which the second bath is composed, (2) the great heat extraction capacity of the aluminum and aluminum base alloys enables the close control of the quenching temperature.

It will be observed that both in the first bath and in the second bath the steel is perfectly wetted by the aluminum or aluminum base alloy of the bath, so that there is virtually a continuous heat transfer path between the interior of the steel member and the highly conductive bath, whereby travel of heat in and out is facilitated. This method thus contrasts with lead and other molten metal bath quenching methods where the article to be heat treated is not wetted and hence heat transmission is imperfect at the interface.

Inasmuch as the steel has been perfectly wetted with aluminum in the first coating bath, immersion in the second bath at a lower temperature arrests the otherwise rapid formation of the ferro-aluminum alloy bond, and in addition hardens the cylinder. Cylinders treated in accordance with our process have, in many instances, a hardness of 55–58 Rockwell C.

When the article has been quenched in the second bath, and the formation of the ferro-aluminum bond arrested, the cylinder barrel, while still wetted by molten aluminum, is transferred to a mold where molten aluminum at its melting point, or slightly above, is poured about the wet cylinder barrel and cooled to form the aluminum muff **30** of any required thickness on the exterior surface of the barrel, as shown in Fig. 4. The quenching in the second bath purposely reduces the temperature of the article below that of the casting metal to preclude reheating of the article during casting to a temperature where the steel structure will be changed. The steel is accordingly not reheated to its critical temperature. Where heat treatment of the steel is not necessary or desirable, the second or quenching bath may be omitted, and the muff **30** cast immediately on the aluminum skin overlying the thin ferro-aluminum alloy formed on the article **10** in the first bath and while said skin is still wet as described.

Figs. 2 and 3 of the drawings disclose a suitable type of mold M for casting the aluminum muff **30** on the cylinder barrel **10**. This mold may be of the split type, including two segments **20** and **21**, in the form of halves of a hollow cylinder having overlapping hinge flanges **22** and **23** at the edges thereof, which are joined by hinge pins **60** permit the two sections to be spread apart. Adjacent the lower end of the mold M in each section **20** and **21** is an inwardly projecting shoulder **24** forming an annular support for the flange **12** on the cylinder barrel. A tapering opening **25** is also provided for receiving the lower end of the cylinder barrel **10**.

The cylinder barrel **10**, still wetted by the molten aluminum, or aluminum base alloy, is placed in the mold M with an asbestos washer **26** interposed between the flange **12** thereon and the shoulder **24** in the interior of the mold. Molten aluminum can then be poured into the upper end of the mold between its wall and the outer wall of the wet cylinder barrel **10** to produce a muff **30** which is bonded securely to the cylinder barrel **10** by the alloy bond described above.

The casting may be cooled by blowing air through the interior of the cylinder barrel **10**, or quenched in oil, and when the aluminum is hardened, the mold may be split to permit removal of the cylinder barrel.

Thereafter the aluminum muff **30** on the barrel may be machined in any suitable way to cut slots therein and to remove unwanted portions thereof to form cooling fins **11** which are bonded tightly to the cylinder barrel, and thus are capable of quick and efficient transmission of heat for cooling purposes.

If desired, prior to machining of the muff **30** on the cylinder barrel, the article may be transferred to a holding furnace for tempering purposes and thereafter quenched in oil to temper it.

It will be understood that the temperatures of the various baths and the times of treatment of the articles being coated and hardened will vary considerably, depending upon the size of the article, and hence its rate of heat transfer, and the type of metal undergoing treatment. However, it has been found that the most satisfactory temperatures for most types of steel in the initial alloying and coating bath will lie in the range between 1525 and 1625° F. The time of immersion in this bath varies widely. For example, in coating wire it has been found that a few seconds are oftentimes sufficient to successfully form a strong ferro-aluminum bond, whereas larger articles may require as much as ten minutes or even more to heat the surface to be coated to the alloying temperature necessary to form a satisfactory bond.

The quenching temperature also may be varied, depending upon the type of crystalline structure to be formed in the metal, but we have found that a temperature between 1000° and 1250° F. is, in most instances, satisfactory for the treatment of steels. The duration of the quenching step will, of course, vary considerably, depending upon the size of the article and the rate at which the heat can be removed therefrom. Ordinarily, with a cylinder barrel of the type described above, a quenching period of one-quarter to five minutes has been found to be entirely satisfactory.

As illustrated diagrammatically in Fig. 6, the sequence of steps of the process may be varied slightly when our process is used only in the heat treatment of steel. As shown in this diagram, the article, for example, a piece of steel, is raised in temperature to between about 1575° and 1625° F., then quenched at about 1100° F. in an aluminum-silicon alloy bath. The quenched article is then quenched in oil, drawn at about 1000° F., and quenched again in oil. Optionally, depending upon the hardness and other physical properties required, the article may be placed in a draw furnace, after the first quench in the second bath, for a suitable period, followed by an oil quench. This is indicated by the dotted curve of Fig. 6.

The high heat conductivity of aluminum at the temperatures involved (1.01 at about 1110°) and the high specific heat of aluminum (.2683) provides a particularly rapid quenching and heat dissipating action and thus allows accurate control of the heat treating operation.

From the foregoing disclosure of the present invention, it will be clear that we have provided

a simple and most effective method of coating articles with aluminum and, if desired or required simultaneously heat treating such articles to produce a high hardness with adequate toughness to withstand the rigorous treatment afforded such articles as cylinder barrels for aeronautical engines, notwithstanding the high temperatures and widely different coefficients of thermal expansion of the aluminum and the steel.

It will be understood from the foregoing that the process disclosed herein is susceptible to considerable variation in the temperatures and times of treatment, depending upon the characteristics of the articles being treated, its composition, and the physical characteristics desired in the finished products. Therefore, the embodiment of the invention disclosed herein should be considered as illustrative only and not as limiting the scope of the following claims.

We claim:

1. A method of directly coating a ferrous metal article with aluminum-containing metal of the class consisting of aluminum and aluminum base alloys, which comprises heating the surface of said article to be coated to a temperature not materially in excess of 1625° F. and above the melting point of said aluminum-containing metal to cause the ferrous metal of said surface to alloy with the said aluminum-containing metal in contact therewith in the molten state, maintaining said heated ferrous metal surface of the article and said molten aluminum-containing metal in contact with each other for a period of time only sufficient to form a film of ferro-aluminum alloy at the interface between them and an initial coating of said aluminum-containing metal on said alloyed surface of the article, casting between said initial coating and a mold spaced therefrom a layer of molten metal of the class consisting of aluminum and aluminum base alloys while said initial coating and said surface are at a sufficiently high temperature for said surface to be wetted by said initial coating, and freezing said coating and layer on said surface whereby said coating and layer are united to form a single coating of said aluminum-containing metal of the required thickness integrally bonded to said surface of the article through said ferro-aluminum alloy.

2. A method of coating metals which comprises immersing a ferrous metal article in a bath of molten metal of the class consisting of aluminum and aluminum-base alloys at a temperature and for a time sufficient to form a ferro-aluminum alloy film on the surface of said article, immersing said article without cooling in a bath of molten metal of the class consisting of aluminum and aluminum-base alloys maintained at a lower temperature than said first bath to arrest alloy formation, to clean the surface of said film and form a molten coating on said article, and thereafter casting a molten metal of the class consisting of aluminum and aluminum-base alloys on said coated surface while the surface of said article is still wet with said molten metal from said second bath.

3. A method of coating metal with an aluminum-containing metal of the class consisting of aluminum and aluminum-base alloys, which comprises contacting a ferrous metal article with molten aluminum containing metal at a temperature between about 1525° and about 1625° F. for a period of time sufficient to form a film of ferro-aluminum alloy on the surface of said article, immersing said article without substantial cooling and while wet with molten aluminum containing metal in a bath of an aluminum-silicon alloy maintained at a temperature between about 1000° F. and about 1250° F. to cool said article, arrest further alloy formation and clean the surface of said film, and subsequently applying to the surface of said article while at substantially the latter temperature a coating of molten aluminum containing metal, and cooling said article.

4. The method of coating a ferrous metal engine cylinder barrel with a layer of an aluminum containing metal having greater thickness than the barrel wall, which comprises immersing the barrel in a bath of metal of the class consisting of aluminum and aluminum-base alloys at a temperature and for a time sufficient to form a film of ferro-aluminum alloy on said barrel, transferring the barrel without substantial cooling to a second bath of a molten metal of the class consisting of aluminum and aluminum-base alloys maintained at a lower temperature than the first bath to arrest further formation of the ferro-aluminum alloy and clean the surface of said alloy film, transferring the barrel without substantial cooling into a mold, and immediately casting a layer of metal of the class consisting of aluminum and aluminum-base alloys on the wetted surface of said barrel to form the layer thereon.

5. The method of coating a ferrous metal engine cylinder barrel or the like with a layer of an aluminum-containing metal of the class consisting of aluminum and aluminum base alloys, said layer having greater thickness than the barrel wall, which comprises immersing the barrel in a bath of a molten aluminum containing metal at a temperature and for a time sufficient to form a ferro-aluminum alloy film on the barrel, transferring the barrel without substantial cooling to a second bath of an aluminum containing metal at a lower temperature than the first bath to arrest further formation of the alloy, transferring the barrel without substantial cooling into a mold, immediately casting a layer of an aluminum containing metal on the wetted surface of said barrel to form the layer thereon, and cooling the barrel interiorly while the aluminum containing metal layer is freezing to induce substantially uniform radial contraction thereof.

6. A method of coating a ferrous metal article with aluminum or aluminum alloys, which comprises forming an initial molten surface coating of a metal of the class consisting of aluminum and aluminum-base alloys on the ferrous metal article by immersing said article in a bath of the molten metal and maintaining said article in contact with said bath for a period of time at the bath temperature only sufficient to form a ferro-aluminum film at the interface of said bath and said article and heat said article to above the melting point of the coating metal, and then casting a molten metal of the class consisting of aluminum and aluminum-base alloys on said initial coating while said coating and article are at a sufficiently high temperature for said coating to be molten and to be wetted by said casting metal to form a permanent bond therewith.

7. A method of directly coating a ferrous metal article with aluminum-containing metal of the class consisting of aluminum and aluminum base alloys, which comprises heating the surface of said article to be coated to a temperature not materially in excess of 1625° F. and above the melting point of said aluminum-containing metal to cause the ferrous metal of said surface to alloy with the said aluminum-containing metal in con-

tact therewith in the molten state, maintaining said heated ferrous metal surface of the article and said molten aluminum-containing metal in contact with each other for a period of time only sufficient to form a film of ferro-aluminum alloy at the interface between them and an initial coating of said aluminum-containing metal on said alloyed surface of the article, casting between said initial coating and a mold spaced therefrom a layer of molten metal of the class consisting of aluminum and aluminum base alloys when said initial coating and said surface are at a temperature within the melting range of said initial coating, so that said initial coating and said layer of molten metal will unite, and freezing said coating and layer on said surface whereby said coating and layer form a substantially homogeneous coating of said aluminum-containing metal of the required thickness integrally bonded to said surface of the article through said ferro-aluminum alloy.

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