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DESCRIPTION

The invention relates to an impervious nickel-chromium coating that when subjected to the standard corrosion test according to ASTM G-61, a current of less than 50 microamperes per cubic centimetre results with an applied potential of 400 millivolts (mV). The invention also relates to a process for producing the coating:

Iron-containing alloys, such as different grades of steel and stainless steels, are subject to corrosion when exposed to aqueous environments. Thermally-sprayed coatings are frequently used in corrosive environments to provide wear resistance. There are many thermal spray coatings whose corrosion characteristics are superior to iron-containing alloys. The use of such wear and corrosion resistant coatings may be limited by the corrosion behavior of the substrate. This is because of the interconnected porosity which is inherently present in thermally-sprayed coatings. This interconnected porosity may allow the corrosive media to reach the coating substrate interface. An example of the problem is the use of a plasma-sprayed Cr_2O_3 coating on a 300 series stainless steel substrate in sea

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water. This coating/substrate combination is frequently used for applications such as mechanical seals. The Cr_2O_3 coating itself has good wear and corrosion resistance, but the stainless steels are susceptible to crevice corrosion. Consequently, Cr_2O_3 coatings on 300 series stainless steels frequently fail in a sea water environment. The fabrication of mechanical seals from nickel base corrosion resistant alloys is expensive. Weld deposited overlays of nickel base corrosion resistant alloys on iron base alloys have both technical and cost problems.

It has now been found possible to provide an impervious coating for a metallic alloy substrate, such as, for example, an iron-containing alloy, a copper-containing alloy, a cobalt-containing alloy, an aluminium-containing alloy, or a nickel-containing alloy, that can be used in aqueous environments. It has also been found possible to provide a process for protecting a metallic alloy from aqueous corrosion by applying an impervious coating to such alloy.

According to the present invention there is provided a process for protecting a metallic alloy from aqueous corrosion which comprises applying an impervious coating to such alloy by the steps of:

- (a) preparing a metallic alloy substrate;
- (b) preparing a powder comprising about 21 to 23 weight percent chromium, about 8 to 10 weight percent molybdenum, about 2.5 to 3.5 weight percent iron, about 3 to 4 weight percent niobium, and remainder substantially nickel; and
- (c) depositing the powder composition of step (b) with a thermal spray device onto the substrate to produce a coating in excess of 0.0889 mm (0.0035 inch) thick and having the characteristics such that when



subjected to the ASTM G-61 corrosion test, a current density of less than 50 microamperes per square centimetre, preferably less than 25 microamperes per square centimetre, results when a potential of 400 millivolts is applied.

According to the present invention there is also provided a coated metallic alloy substrate wherein the coated layer is a barrier coating having a composition of 21 to 23 weight percent chromium; about 8 to 10 weight percent molybdenum; about 2.5 to 3.5 weight percent iron; about 3 to 4 weight percent niobium and remainder substantially nickel; and the .pl72 coating being impervious such that when subjected to the ASTM G-61 corrosion test, a current density of less than 50 microamperes per square centimetre results when a potential of 400 millivolts is applied.

According to the present invention there is further provided a coated metallic alloy substrate having an impervious barrier coated layer of a composition of about 21 to 23 weight percent chromium; about 8 to 10 weight percent molybdenum; about 2.5 to 3.5 weight percent iron; about 3 to 4 weight percent niobium, and the remainder substantially nickel and having a top coated layer of a wear resistant coating.

Achieving a current density of less than 50 microamperes per cm^2 at an applied potential of 400 millivolts will ensure that the coating is impervious and will not permit liquid to penetrate through the coating and contact the surface of the substrate. Thus a wear resistance coating, such as, for example, aluminium oxide, chromium oxide, titanium oxide, mixed oxides of aluminium oxide and titanium, tungsten carbide cermets, tungsten carbide-cobalt cermets, tungsten carbide-nickel cermets, tungsten carbide-



chromium-cobalt cermets, tungsten carbide-chromium-nickel cermets, chromium carbide-nickel-chromium cermets, chromium carbide-IN-625 cermets, and tungsten-titanium carbide-nickel cermets could be deposited on the coating of this invention as a top coat to provide wear resistance for the coated article. This coated article could then be used in an aqueous corrosion environment and the undercoat used in the present invention will prevent any of the aqueous media from penetrating through to the substrate.

Preferably the powder composition of this invention comprises about 22 weight percent chromium; about 9 weight percent molybdenum; about 3 weight percent iron; about 3.5 weight percent niobium; and remainder substantially nickel, such as, for example, about 62.5 weight percent nickel. The thickness of the coating should be greater than 0.0889 mm (0.0035 inch), preferably greater than 0.1016 mm (0.004 inch) and most preferably greater than 0.1524 mm (0.006 inch). One purpose of the coating is to provide an impervious layer for a metallic alloy substrate that will prevent a corrosive media from permeating through the coating to contact the surface of the substrate. Thus a wide variety of substrates can be used in an aqueous environment since the coating used in the present invention will protect the substrate from the corrosive media. Suitable substrates would include various grades of stainless steels such as, for example, AISE 304, AISE 316, or AISE 410 stainless steel, other austenitic, ferritic, martensitic, or precipitation hardened stainless steels, plain carbon steel such as, for example, AISE 1018, and alloy steels such as, for example, AISE 4140. Other substrates could be used such as, for example, copper-base alloys, aluminium-

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base alloys, nickel-base alloys, and cobalt-base alloys.

The coating of this invention could function as a barrier coating onto which a top coat could be applied for a particular application. For example, if wear resistant characteristics are required, a coating such as, for example, chromium carbide cermets, tungsten carbide cermets or oxides could be applied by any conventional method, such as, for example, plasma spraying, flame plating, high velocity oxy-fuel, or detonation gun. The wear resistant top coats that can be used include chromium oxide, aluminium oxide, titanium oxide, mixed oxides of aluminium chromium and titanium, tungsten carbide cermets, tungsten carbide-cobalt cermets, tungsten carbide-chromium-cobalt cermets, tungsten carbide-nickel-chromium cermets, chromium carbide-IN-625 cermets, tungsten carbide-nickel cermets, tungsten-titanium carbide-nickel cermets and chromium carbide-nickel-chromium cermets.

In applying the coating of this invention, the thermal spraying process should be used to ensure that the proper gas temperature and gas pressure are obtained when propelling the powders onto the surface of the substrate. Preferably, the powders of the coating composition used in the present invention should be applied onto the surface of the substrate at a gas temperature from about 1649°C to 3204°C (3000°F to 5800°F) at a gas pressure of from about 11 atm to 18 atm, and to a thickness of at least greater than 0.0889 mm (0.0035 inch). Most preferably, the gas temperature should be from about 1760°C to 3093°C (3200°F to 5600°F) and the gas pressure should be from about 12 atm to about 16.5 atm.



Thus to ensure that the proper gas temperature and gas pressure are obtained, a thermal spraying process should be used. Thermal spraying by means of detonation consists of a fluid-cooled barrel having a small inner diameter of about 25.4 mm (one inch). Generally a mixture of oxygen and acetylene is fed into the gun along with a comminuted coating material. The oxygen-acetylene fuel gas mixture is ignited to produce a detonation wave which travels down the barrel of the gun whereupon the coating material is heated and propelled out of the gun onto an article to be coated. -A- 2 714 563 discloses a method and apparatus which utilizes detonation waves for thermal spray coating.

In general, when the fuel gas mixture in a detonation gun is ignited, detonation waves are produced whereupon the comminuted coating material is accelerated to about 731.5 m/Sr (2400 ft/sec) and heated to a temperature near its melting point. After the coating material exits the barrel of the detonation gun, a pulse of nitrogen purges the barrel. This cycle is generally repeated about four to eight times a second. Control of the detonation coating is obtained principally by varying the detonation mixture of oxygen and acetylene.

In some applications it was found that improved coatings could be obtained by diluting the oxygen-acetylene fuel mixture with an inert gas such as nitrogen or argon. The gaseous diluent has been found to reduce or tend to reduce the flame temperature since it does not participate in the detonation reaction. -A- 2 972 550 discloses the process of diluting the oxygen-acetylene fuel mixture to enable the detonation-coating process to be used with an increased number of



Generally, acetylene has been used as the combustible fuel gas because it produces both temperatures and pressures greater than those obtainable from any other saturated or unsaturated hydrocarbon gas. However, for some coating applications, the temperature of combustion of an oxygen-acetylene mixture of about 1:1 atomic ratio of oxygen to carbon yields combustion temperatures much higher than desired. As stated above, the general procedure for compensating for the high temperature of combustion of the oxygen-acetylene fuel gas is to dilute the fuel gas mixture with an inert gas such as, for example, nitrogen or argon. Although this dilution lowers the combustion temperature, it also results in a concomitant decrease in the peak pressure of the combustion reaction. This decrease in peak pressure results in a decrease in the velocity of the coating material propelled from the barrel onto a substrate. It has been found that with an increase of a diluting inert gas to the oxygen-acetylene fuel mixture, the peak pressure of the combustion reaction decreases faster than does the combustion temperature.

In US-A- 4 902 539 a novel fuel-oxidant mixture for use with an apparatus for flame plating using detonation means is disclosed. Specifically, US-A- 4 902 539 discloses that the fuel-oxidant mixture for use in detonation gun applications should comprise:

- (a) an oxidant and
- (b) a fuel mixture of at least two combustible gases selected from the group of saturated and unsaturated hydrocarbons. The oxidant disclosed is one selected from oxygen, nitrous oxide and mixtures thereof and the like and the combustible fuel mixture is at least two gases selected from acetylene (C_2H_2),



propylene (C_3H_6), methane (CH_4), ethylene (C_2H_4), methyl acetylene (C_3H_4), propane (C_3H_8), ethane (C_2H_6), butadienes (C_4H_6), butylenes (C_4H_8), butanes (C_4H_{10}), cyclopropane (C_3H_6), propadiene (C_3H_4), cyclobutane (C_4H_8) and ethylene oxide (C_2H_4O). The preferred fuel mixture recited is acetylene gas along with at least one other combustible gas such as propylene. Thus, detonation means using one combustible gas or combustible fuel mixtures of two or more combustible gases can be used to deposit the coating used in the present invention, provided the proper combination of temperature and pressure for the coating powders is obtained as described above.

To ensure that the coating used in the present invention is impervious to an aqueous corrosion media, the coating should be capable of producing a current density of less than 50 microamperes per square centimetre when subjected to an applied potential of 400 millivolts according to the ASTM G-61 standard test method for conducting cyclic potentiodynamic polarization measurements for localized corrosion susceptibility of iron-, nickel-, or cobalt-based alloys. This test method describes a procedure for conducting cyclic potentiodynamic polarization measurements to determine relative susceptibility to localized corrosion (pitting and crevice corrosion) for iron-, nickel-, or cobalt-based alloys in a chloride environment. This test method also describes an experimental procedure which can be used to check one's experimental technique and instrumentation. The ASTM G-61 test is a standard test procedure that is readily available at any library and is well known in the art.



The present invention will now be further described with reference to the following Example and as illustrated in the accompanying drawings, in which:

Figure 1 shows a schematic representation of three cyclic potentiodynamic polarization curves for alloys in a 3.5% NaCl solution according to the standard corrosion test disclosed in ASTM G-61;

Figure 2 shows a schematic representation of three cyclic potentiodynamic curves for IN-625 coatings put on different substrates and tested using a 3.5% NaCl solution according to the standard corrosion test disclosed in ASTM G-61.

Example

Using the test procedure of ASTM G-61-86 (-86 means 1986 edition), along with a 3.5% by volume NaCl solution, the electrochemical corrosion studies on bare alloys and coated alloys were conducted. A potentiodynamic cyclic polarization technique was used to evaluate the corrosion behaviour of the coating and alloys. Basically, in these tests about one centimetre square area of the sample is exposed to a corrosive media. A potential scan is started at some potential negative to the open circuit potential (E_{corr}) of the sample. This is termed cathodic polarization, since the sample becomes cathodic with respect to the counter electrode. During cathodic polarization the sample remains protected, and hydrogen evolution occurs at the sample. To study the corrosion behaviour of the sample, potentials more positive than E_{corr} have to be applied; i.e., anodic

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polarization. Starting the potential scan at some potential negative to E_{corr} not only ensures the inclusion of E_{corr} in the scan, but also that the data generated under cathodic polarization can be used for the polarization resistance measurements.

As the potential scan crosses the E_{corr} , corrosion (oxidation) of the sample occurs. The intensity of corrosion is measured by the resulting current between the sample and the counter electrode. The potential scan is reversed at a sufficiently high corrosion rate. Because of this reversal, the technique is termed "cyclic" polarization. Conventionally, applied potential is plotted at the y-axis and the resulting current density is plotted at the x-axis.

The cyclic polarization plots for samples of bare 1018 steel (Sample A), 304 stainless steel (Sample B) and IN 625 alloy (Sample C) are presented in Figure 1 for ready reference as the base line data. In Figure 1, the 304 stainless steel Sample B shows a typical pitting corrosion behavior. Breakdown of passivity occurs at about 200 mV which is marked by the rapid increase in current density due to pit initiation and growth. A hysteresis loop is formed as the direction of the scan is reversed due to continued and accelerated corrosion in the pits.

In Figure 1 the IN 625 alloy Sample C does not show a pitting behavior. Passivity was maintained up to about 550 millivolts. The rapid increase in current which occurs at this potential is not due to pitting, it is due to uniform corrosion of the alloy in the transpassive region. In this region, the passive oxide layer starts to dissolve



oxidatively, generally as a hydrolyzed cation in a higher oxidation state. The reverse scan for the IN 625 Sample B closely followed the forward scan.

Since there were no pits, the corrosion of the alloy
5 at a given potential remained the same in the reverse scan.

In Figure 1 the 1018 steel Sample A shows a very negative corrosion potential (E_{corr} value). The current density continued to rise with the applied
10 potential in the forward direction without a discontinuous change in rate indicating rapid general corrosion.

The current density at 400 millivolts can be taken as the criteria distinguishing between
15 materials that are corrosion resistant and materials that are not, since this potential is above the breakdown potential for alloys susceptible to localized corrosion and below the transpassivation potential for the most corrosion resistant alloys.
20 It has been determined that materials with a corrosion current at 400 millivolts greater than about 50 microamps per square centimetre exhibit excessive corrosion on microscopic examination after the test while those with a corrosion current of less
25 than 50 microamps exhibit no visible corrosion.

In addition to the alloy sample testing, a coating used in the present invention was thermal sprayed onto various alloy samples using the detonation
technique. The coating was deposited at various gas
30 temperatures and gas pressures to various thicknesses as shown in the Table. The coating used in the present invention that was used in the test was IN 625 powder which comprised 22% by weight Cr; 9% by weight Mo; 3% by weight Fe, 3.5% by weight Nb and balance Ni. The

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data obtained from the ASTM G-61 test for both the alloy samples and the coated alloy samples are presented in the Table. A plasma spray process was also used to coat one sample (Sample Q).

Figure 2 compares the polarization behaviour of a coating used in the present invention on both IN-625 alloy (Sample D) and AISE 1018 alloy substrates with a prior art plasma spray coating of a similar composition on an AISI 1018 alloy (Sample Q) substrate. The polarization behaviour of the samples with the coating used in the present invention are not affected by the type of substrate thus exhibiting impervious behaviour, but the plasma spray coated sample of the prior art shows a high corrosion rate of the substrate because the coating is not effectively sealed and the substrate is attacked.

The data in the Table show that an impervious coating of IN 625 powder was obtained when the powder was thermal sprayed at a gas pressure of from 12.0 to 16.7 atm, a gas temperature from 1793°C to 3086°C (3259°F to 5587°F) and a thickness of at least 0.0889 mm (0.0035 inch). The plasma sprayed coating was not impervious nor were the coatings that were deposited outside the gas pressure and gas temperature ranges recited above. As can be seen from the data, impervious coatings can be obtained from a specific powder composition if the powder composition is deposited using the thermal spray technique so that the powders can be applied within a specified gas temperature range and gas pressure range.

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TABLE

Sample	Coating	Substrate	C ₂ H ₂ (Vol %)	O ₂ (Vol %)	N ₂ (Vol %)	C ₃ H ₆ (Vol %)	PFR (g/min)	Temp (F)	Pressure (ATM)	Coating Thickness (in)	Current Density @ 400 mV (UA/cm ²)	Impervious
A	None	1018 St									100000	
B	None	304 SS									7000	
C	None	IN 625									0.8	
D	IN 625	IN 625	12.5	57.5	0.0	30.0	45	3259	15.2	0.007	3	Yes
E	IN 625	IN 625	12.5	57.5	0.0	30.0	60	3259	15.2	0.007	4	Yes
F	IN 625	IN 625	12.5	57.5	0.0	30.0	90	3259	15.2	0.007	9	Yes
G	IN 625	1018 St	12.5	57.5	0.0	30.0	45	3259	15.2	0.007	5	Yes
H	IN 625	1018 St	12.5	57.5	0.0	30.0	60	3259	15.2	0.007	10	Yes
I	IN 625	1018 St	12.5	57.5	0.0	30.0	90	3259	15.2	0.007	20	Yes
J	IN 625	1018 St	26.7	54.6	0.0	18.6	60	4109	16.7	0.007	3	Yes
K	IN 625	1018 St	40.0	52.0	0.0	8.0	60	5487	18.9	0.007	200	No
L	IN 625	1018 St	17.8	20.0	61.5	0.0	60	3240	8.2	0.007	100	No
M	IN 625	1018 St	29.2	28.8	42.0	0.0	60	4450	12.0	0.007	20	Yes
N	IN 625	1018 St	40.2	39.7	20.0	0.0	60	5587	16.0	0.007	5	Yes
O	IN 625	1018 St	12.5	57.5	0.0	30.0	45	3259	15.2	0.004	200	No
P	IN 625	1018 St	12.5	57.5	0.0	30.0	45	3259	15.2	0.0035	25	Yes
Q	IN 625*	1018 St					20			0.007	300	No
R	IN 625	304 SS	12.5	57.5	0.0	30.0	45	3259	15.2	0.007	5	Yes
S	IN 625	304 SS	12.5	57.5	0.0	30.0	60	3259	15.2	0.007	5	Yes
T	IN 625	304 SS	12.5	57.5	0.0	30.0	90	3259	15.2	0.007	5	Yes

*Plasma Sprayed with a standard torch using 120 Amps current, 57 Volts, and Argon gas for shielding.

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CLAIMS

1. A process for protecting a metallic alloy from aqueous corrosion which comprises applying an impervious coating to such alloy by the steps of:

(a) preparing a metallic alloy substrate,

(b) preparing a powder comprising about 21 to 23 weight percent chromium; about 8 to 10 weight percent molybdenum; about 2.5 to 3.5 weight percent iron; about 3 to 4 weight percent niobium and remainder substantially nickel; and

(c) thermal spraying the powder composition of step (b) onto the metallic alloy substrate to produce a coating at least 0.0889 mm (0.0035 inch) thick and having the characteristics such that when subjected to the ASTM G-61 corrosion test, a current density of less than 50 microamperes per square centimetre results when a potential of 400 millivolts is applied.

2. A process according to claim 1, wherein in step (b) the powder composition is about 22 weight percent chromium, 9 weight percent molybdenum; about 3 weight percent iron; about 3.5 weight percent niobium; and remainder substantially nickel.

3. A process according to claim 1 or 2, wherein the thickness of the coating is at least 0.0889 mm (0.0035 inch).

4. A process according to claim 3, wherein the thickness of the coating is at least 0.1016 mm (0.004 inch).

5. A process as according to claim 4, wherein the thickness of the coating is at least 0.1524 mm (0.006 inch).

6. A process according to any of claims 1 to 5, wherein a metallic alloy substrate is selected from AISE 304SS, AISE 316 SS, AISE 410 SS, austenitic

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stainless steel, ferritic stainless steel, martensitic stainless steel, precipitation hardened stainless steel, plain carbon steel, alloy steel, copper-base alloy, aluminium-base alloy, nickel-base alloy, and cobalt-base alloys.

7. A process according to any of claims 1 to 6, wherein the following step is added:

(d) depositing a coating on top of the coating of step (c).

8. A process according to claim 7, wherein the coating in step (d) is selected from the group consisting of chromium oxide, aluminium oxide, titanium oxide, mixed oxides of aluminium oxide and titanium, mixed oxides of aluminium chromium and titanium, tungsten carbide cermets, tungsten carbide-cobalt cermets, tungsten carbide-nickel cermets, tungsten carbide-chromium-cobalt cermets, tungsten carbide-chromium-nickel cermets, chromium carbide-nickel-chromium cermets, chromium-carbide-IN-625 cermets, and tungsten-titanium carbide-nickel cermets.

9. A process according to any of claims 1 to 8, wherein in step (c) the gas temperature is about 1649°C to 3204°C (3000°F to 5800°F) and the gas pressure is about 11 atm to 18 atm.

10. A process according to claim 9, wherein in step (c) the gas temperature is about 1760°C to 3093°C (3200°F and 5600°F) and the gas pressure is about 12 atm to 16.5 atm.

11. A coated metallic alloy substrate wherein the coated layer is a barrier coating having a composition of 21 to 23 weight percent chromium; about 8 to 10 weight percent molybdenum; about 2.5 to 3.5 weight percent iron; about 3 to 4 weight percent niobium and remainder substantially nickel; and the

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coating being impervious such that when subjected to the ASTM G-61 corrosion test, a current density of less than 50 microamperes per square centimetre results when a potential of 400 millivolts is applied.

12. A coated metallic alloy according to claim 11, wherein

(i) the barrier coating has a composition as defined in claim 2; and/or

(ii) the barrier coating has a thickness as defined in any of claims 3 to 5; and/or

(iii) the substrate is as defined in claim 6.

13. A coated metallic alloy according to claim 11 or 12, wherein there is a top coat over the barrier coating.

14. A coated metallic alloy according to claim 13, wherein the top coat is as defined in claim 7.

15. A coated metallic alloy according to claim 14, wherein the substrate is a stainless steel and the top coat is selected from a chromium carbide-containing coating, a tungsten carbide-containing coating, a tungsten carbide-chromium-nickel cermet, a tungsten carbide-chromium cobalt cermet, a chromium carbide-IN625 cermet, and a chromium carbide-nickel-chromium cermet.

16. A coated metallic alloy according to claim 14, wherein the substrate is austenitic stainless steel and the top coat is a chromium carbide-containing coating.

17. A coated metallic alloy substrate having an impervious barrier coated layer of a composition of about 21 to 23 weight percent chromium; about 8 to 10 weight percent molybdenum; about 2.5 to 3.5 weight percent iron; about 3 to 4 weight percent niobium, and the remainder substantially nickel and having a top coated layer of a wear resistant coating.

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