Referees report on paper entitled “Anticorrosion Properties of Zn-Al Composite Coating Prepared by Cold Spraying” by Lu et al (Manuscript No: Coatings 436591)

The following comments are to supplement the details provided in brief in the referee’s report submitted on line, which includes general observations on aspects of the paper, suggested points for revision and aspects that require mandatory revision.

The paper provides information relating to the study on the deposition, structure and associated relevant properties of cold sprayed Zn-Al composite coatings for protection of low alloy steels in marine environments. The coating structure is characterised using SEM and EDS and evaluated in terms of its scratch test adhesion behaviour, corrosion behaviour using potentiodynamic scanning and salt spray testing and microhardness studies. Overall, the topic of cold spraying and various applications provides potential for a detailed, systematic study to be conducted on these types of coatings. Unfortunately, at present the manuscript is unsuitable for publication for several reasons, detailed below. The main reasons being (i) poor use of grammar and poor technical style of writing; (ii) lack of literature on specific aspects of this topic and evidence of the novelty surrounding this study; (iii) flawed experimental in terms of providing a systematic and comparative study for testing, comparing and optimising these coatings; (iv) no in depth, critical discussion of the results obtained, what they mean and comparison with previous work conducted and (v) conclusion lack detail and depth. The referee has commented on these five major aspects in more detail below. Further comments for necessary revision are provided in the pdf of the manuscript and are summarised below:

Major Revision Required

1. Style, Structure and Grammar – The structure and grammar throughout in many places is very poor and doesn’t show a logical progression. Further, sections of the manuscript lack the technical professionalism expected from an engineering manuscript for publication in the open literature It is essential that the document is proof read and amended accordingly by professional proof readers who are specialised in editing scientific and technical documents, prior to publication. There are major grammatical inconsistencies, typographical errors throughout, combined with the style of writing, which makes it hard to read and understand what is being said without going back over it more than once. The reviewer started to amend some of the errors within the manuscript but gave up early in the manuscript as the purpose of the reviewer is to review the technical content and not proof reading for English grammatical construction. At this point, the manuscript is not acceptable for publication. However, the manuscript could be considered for publication further down the track after the grammatical construction is improved considerably and the technical comments are addressed (as below):

2. Introduction – A detailed Introduction is provided in terms of corrosion and biofouling in marine environments and use of cold spray technology to overcome many of the disadvantages of other techniques. However, what is lacking here is a focus on some key aspects, forming the basis for this paper. It is not clear what
the novelty of this research is i.e. what is this research contribution to the existing body of knowledge. In addition, there are several relevant articles focussed on cold spraying of Zn-Al alloys which have not been included in this review. These are detailed below:

- Properties of Zn-Al Alloy Cold Spraying Coatings on Magnesium Alloy, Zhao Hui; Huang Zhanghong; Li Pingcang; Wang Hunian Special Casting & Nonferrous Alloys, v 30, n 8, p 702-4, 2010
- Depositing characteristic of 65%Zn-Al coatings produced by cold gas dynamic spray, Li Hai-xiang; Sun Ming-xian; Li Xiang-bo; Wang Hong-ren; Huang Guosheng Chinese Journal of Nonferrous Metals, v 20, n 7, p 1353-9, 2010
- Corrosion resistance of cold-sprayed Zn-50Al coatings in seawater, Li Haixiang; Li Xiangbo; Sun Mingxian; Wang Hongren; Huang Guosheng Journal of Chinese Society for Corrosion and Protection, v 30, n 1, p 62-6 2010

The Introduction needs to be rewritten to incorporate some of these important references as part of the review and highlight where the gaps are forming the basis for this research

3. Experimental – Generally, good details provided on the methodologies adopted for this study, however the studies are carried out on the coating only deposited under one set of conditions. To improve the academic quality of this manuscript, studies should be conducted on coatings under a range of conditions (variation in the spraying parameters, thickness, etc) to determine optimum conditions. In addition, corrosion studies should be conducted on the (uncoated) base material as a reference point. A systematic, comparative study would enhance the quality of the manuscript and it is essential that more coating conditions, other systems are studied

4. Results / Discussion – More detailed explanation is required for the electrochemical tests. What is happening in the cathodic / anodic regions of the curves, particularly effects of cathodic reactions influencing the system. The corrosion behaviour of the coated system should be compared to the uncoated (base steel) material as a reference point to ascertain the corrosion characteristics of the coating relative to the base material, as this is one purpose of this coating, to provide protection to the substrate if the substrate becomes exposed to the environment through defects / breaks in the coating at any point.
Further, this section is just a description of the results. It is not enough to describe the results but to provide a critical discussion around the results. What is lacking is a detailed, critical discussion on what these results mean, how the results can be explained and interpreted based upon previous studies. Overall it lacks depth as it stands.

5. Conclusions – Conclusions are quite general. They should be more detailed and focussed on the specific findings from this study. In particular, the second one is an expected outcome from studying sacrificial coatings and adds no value to the paper, except confirm that it is indeed a sacrificial coating.

Minor Points for Revision

Specific minor technical points for revision are detailed below. In addition, suggestions are made at various points in the pdf for grammatical revision. However, these are not specifically mentioned below as these should all be incorporated in the general proof reading and grammatical revision as mentioned above.

Abstract

- **Line 10** - Need to include a sentence or two to introduce the purpose of this coating and specifically what is the novelty of this research
- **Line 10** - Type of steel? grade?
- **Lines 14-15** - Poor English. Needs to be rewritten for improved clarity, as it is not clear. do you mean that the coating contained unreacted Zn and Al particles as well as oxidation products?

Introduction

- **Line 27** – Which country?
- **Line 31** – Remove “as the like”, as this is not professional engineering terminology
- **Lines 37-39** - Need to provide reference(s) to back this statement up
- **Line 41** – Is there a need for capitalisation?

Experimental

- **Line 44** – Q345 - What type of steel is this? Low alloy Mn steel? why was this grade selected for the study
- **Line 102** – The selected range is confusing; the cathodic scan should be negative wrt the OCP but the anodic scan should be positive wrt the OCP. Here, both your values are negative wrt the OCP making them both cathodic. I think the value 1.6 V be positive if this is the anodic scan range

Results

- **Lines 128-129** - Need to mark on the diagrams what the light and dark regions represent in Figure 1 (b). The lower half of Figure 1 (c) is the substrate?
- **Line 172** – “10….50” is incorrect terminology, write "10 to 50" or "10-50"
• Lines 147-148 - How does these adhesion values compare with literature values of cold sprayed coatings, particularly Zn-Al coatings?

• Lines 151-152 - What is uniformly distributed? Zn rich and Al rich regions?

• Line 152 – Regarding the compact structure of the coating, how do you know this? From the cross-section micrograph? Did you measure porosity to quantitatively assess this?

• Line 152 – Regarding oxidation, how is this confirmed? Did you scan for oxygen in the EDS? Your analysis of the scratch test states the contrary saying that the initial irregularity at 10N is associated with an oxide layer.

• Line 160 - The OCP value is much more positive than the Ecorr values indicating that the corrosion process is influenced strongly by the cathodic reactions, thus shifting the Ecorr value. This should be discussed in detail. The authors should consider doing further tests whereby cathodic and anodic scans are conducted separately on separate, but identical samples, starting at the OCP (i.e, OCP to OCP-0.8 V and OCP to OCP+1.2V respectively)

• Lines 161 - It is not clear, but I assume that you mean potentiodynamic scans were conducted after immersion in the electrolyte for these periods of time. Is this correct? Also, I assume that a fresh sample, and not the same one, was used for each of the electrochemical tests after immersion at the different time periods.

• Line 164 Are the units of mA correct. They are very low. Your graphs suggest that the units that Icorr values are micro-amp range, not nano-amp. I think the units should be in A not mA

• Lines 165-166 – What evidence have you got to support this?

• Lines 189-191 – How do you know this? This cannot be confirmed from EDS alone. You need to use other techniques such as XRD or XPS. The line scan does suggest that the crystallites are predominantly Zn based. It also suggests that NaCl is present, possibly as dehydrated crystals on the surface, but this has not been mentioned or discussed

• Lines 197-204 - I am not clear about the rationale for conducting hardness tests on the corroded samples. Yes, the corroded layer is going to be harder than the base coating due to the formation of oxides / hydroxides. What you are saying is that the coating service life is potentially improved in terms of ability to resist deformation under loading. This may be fine if a compact, well adherent, stable oxide layer can be generated, but there is no evidence or any discussion surrounding this. What about the degradative effects of corrosion, cracking and spallation of the corrosion layer formed, etc? This section needs much more information from the literature to support the rationale for this study. Further, regarding the number of microhardness readings, if you have taken three readings (which I believe is the bare minimum; ideally you should take around 5-10 over the sample surface), you should show the deviation in the readings.
Anticorrosion Properties of Zn-Al Composite Coating Prepared by Cold Spraying

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Abstract: The Zn-Al composite coating was prepared on steel substrate by cold spray technique. The mass fraction of Zn and Al in the raw material was 2:3. The microstructure of the original coating was observed by scanning electron microscopy (SEM) and was characterized by Energy Dispersive Spectrometer (EDS). The composite alloy coating obtained by cold spraying showed that the Zn and Al particles were uniformly distributed with oxidation products, and the powder particles were prominent, Plastic deformation, and the microstructure of the composite coating is very dense. It has a strong adhesion to the substrate, then use the scratch tester to measure the adhesion verification. As a result, Neutral salt spray test (NSS) and electrochemical accelerated corrosion test results showed that Zn-Al composite coating can effectively provide corrosion protection.

Keywords: cold spray; Zn-Al composite coating; corrosion; microscopic morphology

1. Introduction

In the context of large-scale development and utilization of marine resources, marine transportation, fisheries, and maritime military are inseparable from offshore equipment. However, a large amount of natural electrolytes forms a corrosive environment, which causes serious damage to the surface of offshore equipment. As a result, Corrosion and fouling bring great losses to the country. Therefore, it is of great significance to effectively protect metal materials in the marine environment. The research on marine metal materials has also received extensive attention from scholars [1-5].

At present, the surface treatment methods commonly used on the surface of marine equipment include thermal spraying, organic coating, hot dip plating, and the like [6-9]. In the preparation of thermal spray coating, it becomes semi-molten or molten during the thermal spraying process. The alloy coating will grow and oxidize to some extent, and the porosity of the coating will be high with large thermal stress. It will aggravate the corrosion of the entire surface of the entire offshore equipment, resulting in greatly shortened equipment life; organic materials are easily volatilized during the coating process, not only polluting the environment, but also aging the organic coating. Meanwhile, it is also easy to be washed away and scratched in the spray splash area. In recent years, cold spray technology has been used to prepare anti-biofouling and anti-corrosion coatings for offshore equipment. Cold spray technology has shown good application prospects in surface treatment in this field.

Cold spray technology, also known as Cold Gas Dynamic Spray, is a new type of spray technology that has been rapidly developed in recent years. It uses compressed gas (nitrogen, helium,
air, and etc.) as an accelerated gas stream to drive powder particles (size of 1–50 μm) to collide with the substrate at a low temperature (room temperature to 600 °C) and a supersonic speed (300–1200 m/s) to complete solid state, so that the particles will undergo a strong plastic deformation and deposit to form a coating [10-16]. Compared with the traditional painting, thermal spraying and other processes of offshore equipment, the low-temperature characteristics of cold spraying has the following advantages: (1) The cold working environment has a low temperature and it result in a fast deposition coating speed, so there is a wide range of substrate can be applied. It is portable to the entire surface of offshore equipment and is also suitable for the surface of equipment of various bases. (2) The thermal effect on the substrate and the powder particles is negligible, and the oxidation, burning loss, phase transformation and tissue change of the spray powder can be avoided. Meanwhile, the coating of the heat sensitive material such as the nanometer amorphous material is obvious. As a result, the advantage is that there are fewer oxidation products during the preparation process [17-20]. (3) Forming a coating has a low porosity and denseness. Cold spraying in the working process, the subsequent particle can effectively combine with the front deposition coating, and the structure of the coating is also relatively dense. At the same time, the temperature of the coating prepared by cold spraying will not change significantly, so it will not have a thermal expansion and contraction of the coating volume, which can greatly reduce the void ratio of the coating. (4) The coating has a strong protection performance. Compared with the traditional organic coating, the cold spray coating not only is resistant to wear, and it can also can effectively carry out the electrochemical protection of the offshore equipment base in the case of wear of the coating [21].

The initial results show that zinc layer provides the best electrochemical protection for steel [22-24], but its long-term protection against high-chlorine or offshore steel structures is not good. Aluminum is well-stabilized [25], and thermal sprayed Al coatings have higher hardness, longer durability and higher erosion resistance [26], but aluminum coatings are less electrochemically protective than zinc coatings. The Zn-Al coating is a promising alloy coating that replaces the Zn and Al coatings. Therefore, the purpose of this study is to investigate the corrosion resistance properties of Zn-Al composite coatings in order to facilitate their application in offshore equipment.

2. Experimental Methods

The raw materials used in this study were spherical Zn and Al powder particles, whose size was 1-50μm, and the mass fraction of Zn and Al powder was 2:3, and the mixture was stirred for 1 hour in a ball mill to obtain the mixed powder of sprayed raw materials. The base material is made of 20×60×2mm Q345 steel plate, and the surface is sandblasted, scaled and cleaned.

The coating was prepared using a cold spray technique (DyMET 423). At the center of the cold spray equipment is the gun mechanism, which is equipped with a high-pressure gas pipeline, a heater, a powder feeding pipe and a de Laval nozzle (2 mm in diameter). The overall gun mechanism is mounted on a six-degree-of-freedom robot arm and the compressed power gas is nitrogen. The pressure is 1.8 MPa and the working temperature is 400 °C. The spray gun is 20 mm away from the spray substrate and the powder particles are sprayed at 800 m/s.

The apreo scanning electron microscopy (SEM, FEI, Apreo, Czech Republic) was used to study the microscopic morphology of the composite coating. The surface morphology of the coating, the plastic deformation of the Zn-Al powder particles, the pores of the coating, and the mixing of the spray of Zn-Al can be observed by monitoring the microstructure of the coating by SEM. In addition, the cross section of the coating can also be intuitive and the state of bonding of the coating to the substrate can be observed. The Energy Dispersive Spectrometer (EDS) is used to measure the different features of the coating and the distribution of elements.

The scratch function of the Multi-Function Material Surface Performance Tester(MFT-4000, USA) was used to determine the adhesion of the composite coating. In the scratch test, a 120° stylus probe was selected, and the stylus loading speed was set to 100 N/min, the scratch length was 10 mm, and the termination load was 100 N.

The composite coating was investigated by neutral salt spray (NSS) and electrochemical accelerated corrosion tests method to evaluate the corrosion resistance of the composite coating. A
sample having a surface area of 10 × 10 mm 2 was prepared before the test. Neutral salt spray test in a static environment, where the ambient temperature of the salt spray is stable at 35 ± 1 °C, and 100 ml of 3.5 ± 0.5% NaCl solution at 100% relative humidity is prepared, and its pH is between 6.5 and 7.2. The neutral salt spray test equipment used is model LRHS-108-RY and it includes an atomizing nozzle to atomize the salt solution in the chamber, the salt solution pool, the sample supports the vertical direction of 15° to 20°, the heating element and the controller, as well as the humidification tower, is connected to the reservoir. In the electrochemical accelerated corrosion experiment, the accuracy of the impact test is prevented. The non-coated surface is sealed, and the polarization curve is obtained by scanning. The scanning rate is 0.5 mV / s, from -0.8 V / OCP to -1.6 V / OCP, and test data is recorded each time.

The hardness of the coating was measured by using an automatic turret digital microhardness tester (HXD-1000TM, Shang Hai). The indenter was selected from Vickers diamond, and the program was self-controlled to maintain the load mode. The load was 0.4903 N and the time was 20 s. Three points on the surface of the coating were randomly selected for testing, and the microhardness of the coating was replaced by the average value.

3. Results and discussion

3.1. Microstructure of Zn-Al composite coating

Figure 1 shows a typical surface topography of a Zn-Al composite coating seen from the SEM micrograph. As shown in Figure 1(a), the composite coating is magnified 50×, and it can be visually observed that the distribution of the two metal powders in the layer is uniform. It indicates that the mixing of the Zn and Al powder particles is uniform; as shown in Figure 1(b) The composite coating is enlarged by 1000 times, and two kinds of bright and dark elements can be clearly observed. As a whole, there is no obvious gap on the composite coating, which is smooth; as shown in Figure 1(c), it is a composite coating. Zooming in on the 500× section, it was found that the bright and dark powders were in the shape of a ribbon, distributed evenly and with few voids, and closely adhered to the substrate. According to the two angles of Figure 1(b) and Figure 1(c), it was found in the coating, the two metal powder particles showed a flat shape, and the Zn, Al powder particles were severely plastically deformed when sprayed onto the substrate, thereby obtaining a dense lamellar structure.

The ratio of zinc to aluminum in the coating is 2:3, but the density of zinc is greater than the density of aluminum, so the volume of aluminum is large, and Zinc-rich group has a little portion in the coating and therefore we observed bright color from it. However, Aluminum-rich group has a much larger portion and it performs dim color. The EDS map analysis was performed by the dot to verify the guess.
Figure 2 is a spectrogram measured by an energy dispersive spectrometer (EDS), Table 1 chemical compositions of the Zn-Al coating according to EDS analyses. According to the 1 and 2 point maps, the zinc content in the coating at 1 point is 85.9%, and the aluminum content is only 1.6%; at 2 points the zinc content in the coating is only 0.1%, and the aluminum content is 90.6%. Therefore it can be concluded that the bright metal portion is a zinc-rich group and the dark metal portion is an aluminum-rich group. It is also shown from the energy spectrum of 1 and 2 points that there is almost no oxidation of the composite coating sprayed by the cold spray technique.

![Figure 2. Energy Dispersive spectrometer (EDS) dot spectrogram.](image)

Table 1. Chemical compositions of the Zn-Al coating according to EDS analyses.

<table>
<thead>
<tr>
<th>HEACs</th>
<th>Regions</th>
<th>Elements (at.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn-Al coating</td>
<td>1 (bright)</td>
<td>85.9 1.6 4.6 8.2</td>
</tr>
<tr>
<td></td>
<td>2 (gray)</td>
<td>90.6 0.1 7.8 1.5</td>
</tr>
</tbody>
</table>

The scratch test data of the MFT 4000 multi-functional surface performance tester is shown in Figure 3, where the red line indicates the acoustic signal, the green line indicates the friction, and the black line indicates the friction factor. As shown in the experimental data in Figure 3, the acoustic signal has two mutations. Each mutation represents that the needle is drawn into the material of different components, and it results in an increase in friction factor and friction. The first mutation loading force is about 10N, and it can be observed that the scratcher breaks the coating oxide film; the second mutation loading force is about 55N, and the scratcher can be determined to break the composite coating. The adhesion of the composite coating obtained during the test was 55 N, so that the composite coating could be firmly attached to the surface of the substrate.

![Figure 3. scratch test of composite coating.](image)
In general, the Zn-Al composite coating prepared by the cold spray technique is uniformly distributed with high adhesion and it has a compact structure with no oxidation.

3.2. Corrosion behavior of the coating

The electrochemical accelerated corrosion test measures the open circuit voltage and the polarization curves at different times as shown in Figure 4 below. The corrosion potential \( E_{\text{corr}} \) characterizes the thermodynamic stability of the tested samples under the electrochemical corrosive condition [27]. The corrosion current density \( (i_{\text{corr}}) \) implies that the corrosion rate and breakdown potential were the lowest potential values at which pitting occurred [28]. The corresponding electrochemical parameters of tested samples are all listed in Table 2. The open circuit voltage was record at the beginning of the test and the open circuit potential of the coating was around \(-0.84\) V.

Figure 4 shows the accelerated corrosion plan of 24h, 48h, 72h, and 96h. The data shows that the polarization is accelerated corresponding to the accelerated corrosion time. As the corrosion potential \( (E_{\text{corr}}) \) gradually increases from \(-1.396\) to \(-1.325\) V, the current density gradually decreases from \(1.154 \times 10^{-5}\) to \(1.737 \times 10^{-5}\) mA cm\(^{-2}\), and the corrosion rate can be gradually slowed down. The reason is that the coating began to experience a vigorous electrochemical reaction in the NaCl solution, which generates an oxidation product that hindered the rate of corrosion. In order to probe deeper the corrosion resistance of the coating, the NSS test was conducted.

Table 2. Fitted parameters of polarization curves for the Zn-Al coatings after immersion of 24 h, 48 h, 72 h and 96 h in 3.5 wt.\% NaCl solution.

<table>
<thead>
<tr>
<th>Times/h</th>
<th>( E_{\text{corr}} ) (VSCE)</th>
<th>( i_{\text{corr}} ) (mA cm(^{-2}))</th>
<th>( B_a ) (mV dec(^{-1}))</th>
<th>( B_c ) (mV dec(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>(-1.396 \pm 0.03)</td>
<td>(1.154 \times 10^{-5})</td>
<td>2.743</td>
<td>8.729</td>
</tr>
<tr>
<td>48</td>
<td>(-1.384 \pm 0.04)</td>
<td>(1.248 \times 10^{-5})</td>
<td>2.571</td>
<td>8.134</td>
</tr>
<tr>
<td>72</td>
<td>(-1.351 \pm 0.01)</td>
<td>(1.456 \times 10^{-5})</td>
<td>2.397</td>
<td>8.222</td>
</tr>
<tr>
<td>96</td>
<td>(-1.325 \pm 0.02)</td>
<td>(1.737 \times 10^{-5})</td>
<td>2.375</td>
<td>7.915</td>
</tr>
</tbody>
</table>

Figure 4. Potentiodynamic polarization curves of the Q345 steel substrate, Zn-Al coating in 3.5 wt.% NaCl solution.

Figure 5 is a typical corrosion morphology after corrosion in a 3000 x neutral salt spray (NSS) test. According Figure 5, which is corroded for 24 hours, and the surface layer of the coating has a large number of agglomerate structures, and the voids have a dense needle-like and lamellar structure; Figure 5(b) is corroded for 48 hours. A large number of needle-like and lamellar structures appear in the lumps; in Figure 5(c), the flaky material on the surface of the coating gradually decreases, and the needles gradually increase; in Figure 5(d), the surface of the coating is etched for
96 hours. Cracks have occurred, and there are also a large number of needle-like, lamellar structures in the cracks.

Figure 5. The surface of the coating is magnified 3000× in different corrosion times: (a) 24h; (b) 48h; (c) 72h; (d) 96h.

The EDS linear scanning corrosion coating is shown in Figure 6. It contains a large amount of Zn, Al, and Cl elements on the white agglomerates, and the needle-like morphology contains a large amount of Al elements, and the content of Zn elements is small. In Figure 6, Al was not corroded and remains in its original state. But the Zn was severely corroded, the resulting corrosion products are mainly zinc hydroxide (Zn(OH)$_2$), basic zinc chloride hydrate ZnCl$_2$·4Zn(OH)$_2$·H$_2$O, basic zinc carbonate hydrate Zn$_4$CO$_3$(OH)$_6$·H$_2$O. The crack appearing in Figure 5(d) is because the crack is a Zn-rich group, and Zn is preferentially corroded, so cracks are generated.

Figure 6. Coating EDS line scan after NSS test.

Figure 7. Microhardness of coatings on different corrosion time.
Figure 7 shows the line graph displays the surface hardness of the coating at different corrosion times. The hardness of the uncorroded coating is about 78.667 HV, and it decreases slowly in the first 24 hours. But corrosion increases with the corrosion time, the hardness of the coating also gradually increased. When the corrosion was 96 hours, the hardness of the coating was 139.805 HV. The results show that the initial oxidation of the coating surface is accompanied by a decrease in the hardness of the coating. When the corrosion rate is slow and the oxide film is formed by corrosion passivation, the hardness of the coating is gradually increased. The greater the hardness of the coating, the stronger the ability to resist the pressing of hard objects into the surface.

In summary, Figure 5 and Figure 6 conclude that in the salt spray test, the Zn-Al composite coating will corrode Zn first, and a large number of clusters will gradually corrode, then obtain dense needle-like, lamellar oxidation. The product; the rate of corrosion gradually slows over time, resulting in a passivation film that further reduces corrosion and thereby protects the coating matrix. Even if the coating is scratched, the composite coating has cathodic protection to the substrate. Therefore, the Zn-Al composite coating has good corrosion resistance.

4. Conclusion

In this experimental study, the Zn-Al composite coating sprayed on the Q345 substrate was used to investigate the corrosion resistance of the composite coating. The following conclusions can be drawn:

- The Zn-Al composite coating prepared by cold spray technology has a compact structure, no oxidation during spraying and a uniform material distribution, and high adhesion.
- On the one hand, the composite coating isolates the substrate from contact with the marine environment, thereby avoiding corrosion of the substrate; on the other hand, the coating can cathodically protect the substrate even if the composite coating is scratched and leaked out of the substrate. As the corrosion time of the composite coating increases, its surface hardness is also higher than the original state. Therefore, the coating has good properties as if it were.

Author Contributions: S.W. developed an experimental plan. C.L. wrote the main part of the manuscript. C.L. and G.W. carried out the preparation of different composite materials and tested the mechanical properties. C.L. and G.W. performed characterization of the microstructure of the samples. C.L. and D.W. made the final typesetting of the article. S.W. summed up the article and conducted a final review.

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References


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