

# Research on the Corrosion Resistance of Cast Austenitic Stainless Steel Reinforced by Modified SiC Nanopowders

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## Abstract

The austenitic stainless steel materials modified with nano-SiC powder were prepared under the production conditions by foundry method. The corrosion resistance for different amount of SiC added to stainless steel was investigated. The results showed that with the addition of nano-SiC powder, the resistance to chemical corrosion and electrochemical corrosion was markedly improved. The addition of nano-SiC powders can significantly enhance the intergranular corrosion of stainless steel, and the anti-intergranular corrosion of the stainless steel was the result shown both by the metallographic and the bending methods. With the addition of nano-SiC powder, the ferritic and chromium of the stainless steel reduce segregation, so nano-SiC powders can help effectively avoiding the two-phase chromium depleted zones and areas prone to localized corrosion, such as the emergence of the region.

**Key words:** modified SiC nanopowders, austenitic stainless steel, corrosion resistance, pitting corrosion resistance, intergranular corrosion resistance

## 1. INTRODUCTION

Nowadays, 18-8 austenitic stainless steel is most widely used. The steel has not only good low-temperature toughness, ductility, weldability, corrosion resistance and non-magnetic properties, but also anti-chemical and anti-corrosion ability of electrochemical corrosion at room temperature [1, 2], but damage often occurs under some high-intensity working conditions. To further improve the performance of such stainless steel, many researches done in the world also achieved good results [3–6], in which grain refinement is to increase its strength rather than an effective way to reduce the plastic. In this study, after the surface modification of nano-SiC powder, commonly used austenitic stainless steel for the test material, prepared under the conditions in the production of nano-SiC content in different samples of stainless steel, stainless steel was studied at the intergranular corrosion and corrosion. SiC particles with high strength, high hardness, high mod-

ulus, low expansion coefficient, and other attributes, are an ideal reinforcement. At present, SiC powder reinforced metal matrix composites are actively studied and used, but the cost of SiC particles is too high.

## 2. MATERIALS AND METHODS

The nano-SiC powder with particle size 20–80 nm surface-modified in pre-treatment is used in the test. The raw material for casting is austenitic stainless steel 0Cr18Ni9, its chemical composition is (mass %): 0.079 C, 1.22 Mn, 0.69 Si, 0.007 S, 0.033 P, 18.02 Cr, 8.20 Ni. Medium frequency induction furnace melting was performed at melting temperature of 1600 °C. Respectively, the mass fractions of 0.01, 0.05, 0.1 % of the nano-SiC powder are added into tundish, the molten steel into the holding after 3 min, cast to size 30×260 mm shell type, the natural cooling after four groups of different nano-SiC content in the stainless steel powder.

The study was carried out on samples prepared by the pitting chemistry immersion test, pitting corrosion electrochemical test and intergranular corrosion test, in which pitting corrosion chemical immersion test was made with pure hydrochloric acid and deionised water: 0.05 mol/L hydrochloric acid solution, ferric chloride ( $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ ) 100 g into 900 ml 0.05 mol/L of hydrochloric acid. Potentiodynamic method was used for stainless steel in neutral 3.5 % sodium chloride solution (this study needs to be adjusted in accordance with 3.5 % ferric chloride solution) in the pitting potential. Intercrystalline corrosion of austenitic, austenitic-ferritic stainless steel was detected in the sulphuric acid copper-copper sulphate solution.

### 3. RESULTS AND DISCUSSION

#### 3.1 Pitting corrosion

The pitting corrosion chemical immersion test results for stainless steel without or with nano-SiC powder are shown in Table 1.

Pitting corrosion resistance of stainless steel without or with SiC nanopowders is illustrated in Fig 1.

(1) The average corrosion rate of the sample and the average density are 39.685  $\text{g}/(\text{m}^2 \cdot \text{h})$  and 10.795  $\text{cm}^2$ .

(2) When the content of nanopowders were 0.01, 0.05 and 0.1 %, the average corrosion rate of stainless steel were 34.065, 38.905 and 33.315  $\text{g}/(\text{m}^2 \cdot \text{h})$ , respectively, so, with respect to the samples without nano-SiC powder, a decrease in corrosion rate by 14.16, 1.97 and 16.05 % is observed; The average hole density is, respectively, 5.775, 7.67 and 7.475  $\text{cm}^2$ , compared to the samples without nano-SiC powder a decrease in hole density by 46.5, 28.95 and 30.75 % occurs. It can be seen that the addition of nanopowders to stainless steel

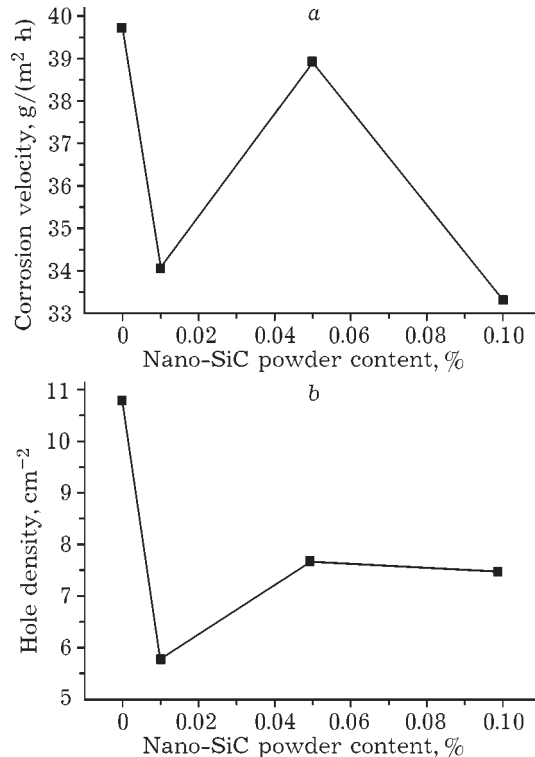


Fig. 1. Pitting corrosion resistance of stainless steels without or with SiC nanopowders.

material greatly enhanced the corrosion resistance.

In 6 % ferric chloride solution, after 24 h of chemical immersion test, the surface morphology of the macrosample of the stainless steel without or with nano-SiC powder is shown in Fig. 2. In general, the pitting corrosion of stainless steel was found in the non-metallic inclusions of metal surfaces, precipitates, grain boundaries, surface defects such as dislocation, more vulnerable as a result of passive film, in particular due to the role of corrosion medium. From pitting corrosion mechanism it can be seen that starting from the material, the improvement of the purity of stainless steel and lower steel inhomogeneity can effectively improve the pitting resistance of the material.

TABLE 1

Pitting chemistry immersion results for stainless steels

Nano-SiC powder content, %	Largest surface area, $\text{cm}^2$	Largest number of surface pitting hole
0	11.355	122.5
0.01	11.255	65
0.05	11.220	86
0.1	11.250	84

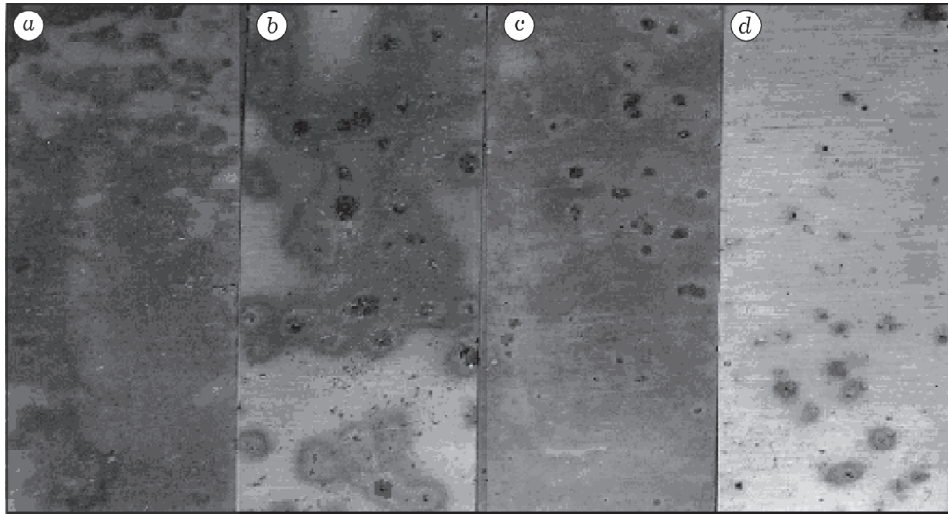


Fig. 2. Pitting corrosion appearance for stainless steels without or with SiC nanopowders, %: 0 (a), 0.01 (b), 0.05 (c), 0.1 (d).

We can see from Fig. 2 that pitting corrosion resistance performance markedly improved after adding nano-SiC powder to stainless steel, and the content of 0.1 % produces the most obvious effect.

### 3.2 Pitting corrosion electrochemical test

**Pitting corrosion potential.** The pitting corrosion electrochemical test of stainless steel was accomplished at 25 °C, in 3.5 % ferric chloride (standard for sodium chloride) solution, using LK98B electrochemical computer analysis system to determine the curves for stainless steel materials as shown in Fig. 3.

As seen from the graph, the addition of nanopowders to stainless steel material greatly

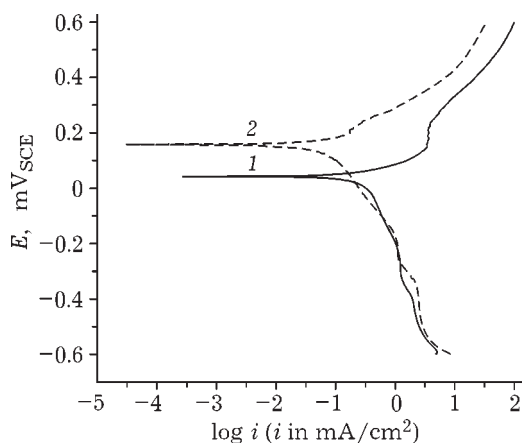


Fig. 3. Electric potential results ( $E$ ) of stainless steels without (1) or with 0.1 % (2) SiC nanopowders.

increased the corrosion potential. When the nanopowder content is 0.1 %, the corrosion potential of stainless steel is about 0.16 mV, far higher than that of stainless steel without SiC nanopowders sample (approx. 0.04 mV).

**Pitting corrosion morphology and energy spectrum.** By pitting morphology, we can see that the surface corrosion of original stainless steel is very serious, the corrosion of stainless steel on adding nano-SiC powder is minor. Smooth surface pitting pit shows the characteristics of uniform corrosion. We can see from the spectrum curve that pitting corrosion occurred in the chromium-depleted zone, the original stainless steel pitting corrosion occurred in the matrix of the regional iron corrosion has basically been lost. The remaining non-metallic elements such as silicon, added with nano-SiC powder to stainless steel lead to pitting corrosion occurring in the chromium-depleted region; it is not very clear that this did not happen with the site of serious pitting in line. Nanopowder can be seen to add refinement to the organization and the role of chromium in stainless steel homogenisation pitting resistance. Chromium-depleted zones have electrode potential lower than the chromium-rich zone, when the material as a result of segregation caused by a large number of Cr-depleted zones exists, the internal potential will result in different materials, when materials and corrosive medium, such as chlorine ion contact, chloride ions in the material first chromium depleted



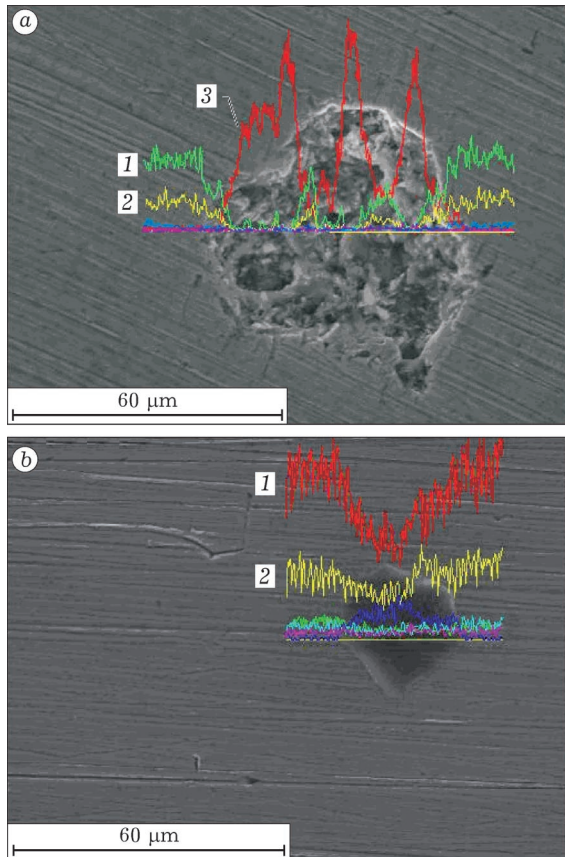


Fig. 4. EDX analysis results of the pitting corrosion pit on the stainless steels without (a) or with 0.1 % (b) SiC nanopowders: 1 - Fe, 2 - Cr, 3 - Si.

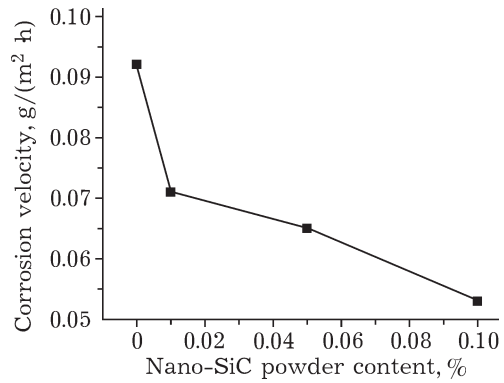


Fig. 5. Intergranular corrosion resistance of stainless steels without or with SiC nanopowders.

zone (part of the passive film defects such as inclusions, chromium-depleted zone, grain boundaries, *etc.*) invasive passive film, combined with metal ions and dissolved salts to form strong passive film and thus to form the microcell, resulting in pitting corrosion and in material damage.

### 3.3 Intergranular corrosion test

The intergranular corrosion of stainless steel is studied in sulphuric acid-copper sulphate so-

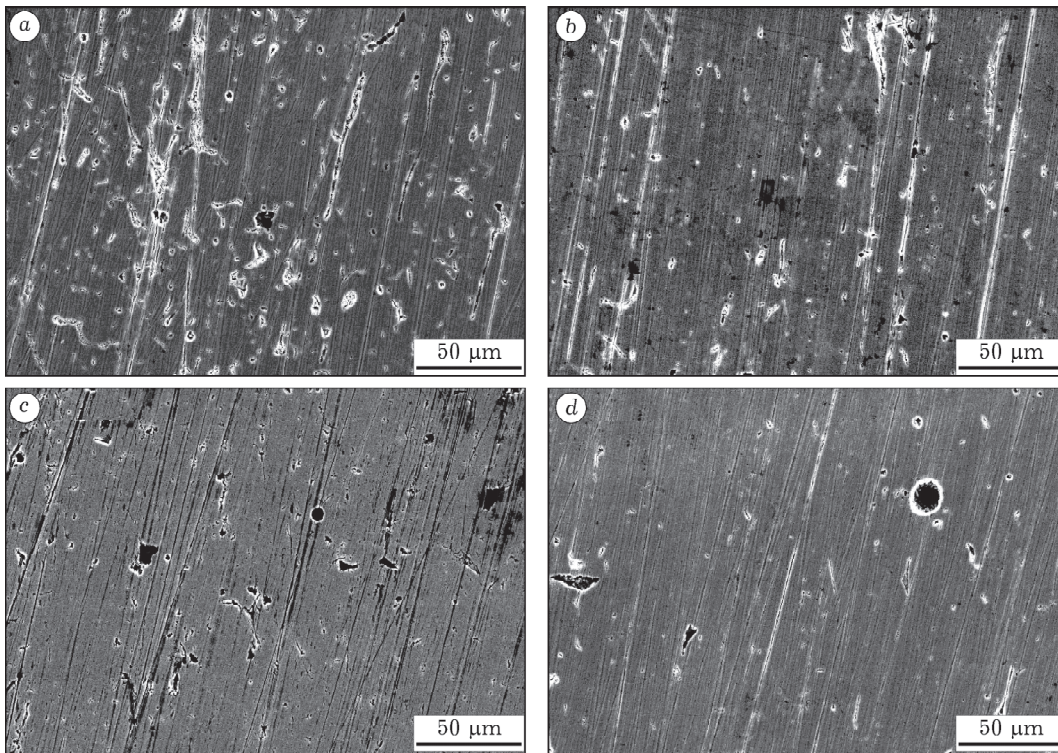


Fig. 6. Intergranular corrosion appearances of stainless steels without or with SiC nanopowders, %: 0 (a), 0.01 (b), 0.05 (c), 0.1 (d).

lution. It can be seen that before and after adding nano-SiC powder, the average corrosion rate of stainless steel decreases as shown in Fig. 5.

As seen from Fig. 5, the addition of nano-SiC powder significantly increased the resistance of stainless steel to intergranular corrosion. When the content of nanopowders was 0.01 and 0.1 %, the average corrosion rate of stainless steel was reduced by 42.39 and 22.83 %. The surface morphology after corrosion is shown in Fig. 6.

The intergranular corrosion of stainless steel without adding nano-SiC powders occurred along the grain and covered the entire surface. In contrast, adding nano-SiC powder to stainless steel the occurrence of intergranular corrosion reduces while for more and more light, intergranular corrosion resistance can increase significantly.

The addition of nano-SiC powder to stainless steel materials makes them fine. Casting alloys, for example, have more refined grain size, grain boundary carbides and non-metallic inclusions are more dispersed, reducing the segregation of impurities, resulting in improved resistance of stainless steel to intergranular corrosion.

The intergranular corrosion on the bending sample is assessed. Bending test specimen in the We-300 hydraulic universal testing machine on the bend of 90°, its morphology as shown in Fig. 7, needed to power the largest bending as shown in Fig. 8.

It is clear from Fig. 7 that stainless steel specimen cracks were produced due to which the sample without SiC nanopowder have intensive and large cracks, while after by adding nanopowder the samples have very few and narrow crack, 0.1 % of it is the most obvious. As seen from Fig. 8, no nano-SiC powder sample by 90° bending of the greatest need for bending 2200 N; in contrast, adding nano-SiC powder of 0.01, 0.05 and 0.1 % of the largest stainless steel bending strength of 2900, 2400 and 2350 N, were increased by 31.82, 9.09 and 6.82 %. This shows that adding nano-SiC powder effectively increases the intergranular corrosion resistance of the original stainless steel.

For the metallographic samples taken from the non-bending part of the sample, the post-erosion (erosion died not happen), then observed under SEM and the corrosion region

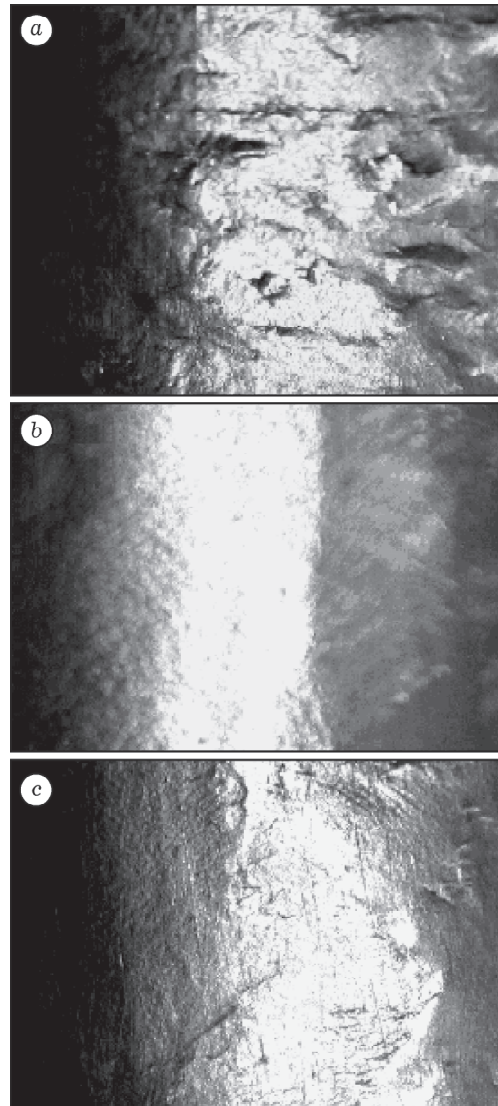


Fig. 7. Intergranular corrosion appearance of stainless steels without or with SiC nanopowders, %: 0 (a), 0.01 (b), 0.1 (c).

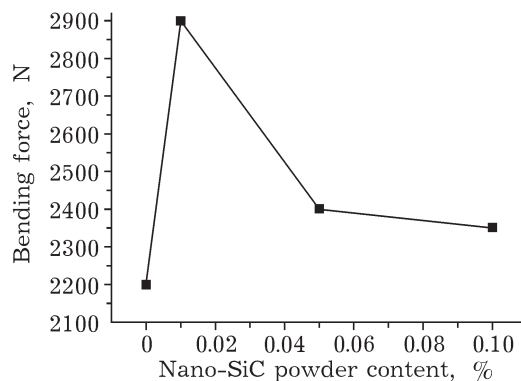


Fig. 8. Bending force of stainless steels without or with SiC nanopowders.



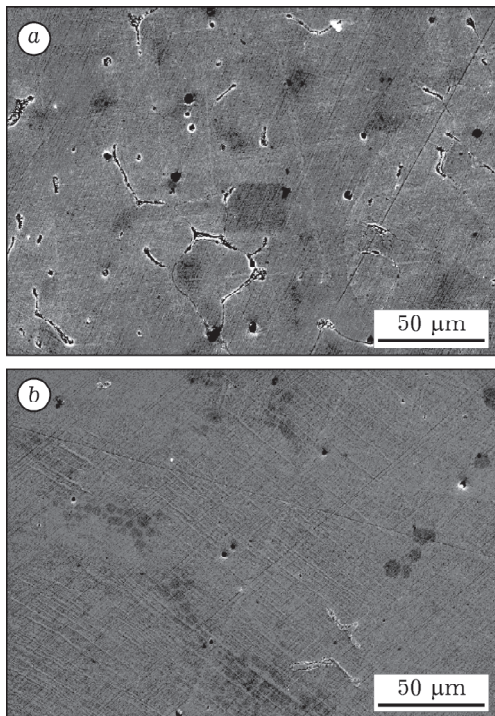


Fig. 9. Intergranular corrosion appearance of the stainless steels without (a) or with 0.1% (b) SiC nanoparticles.

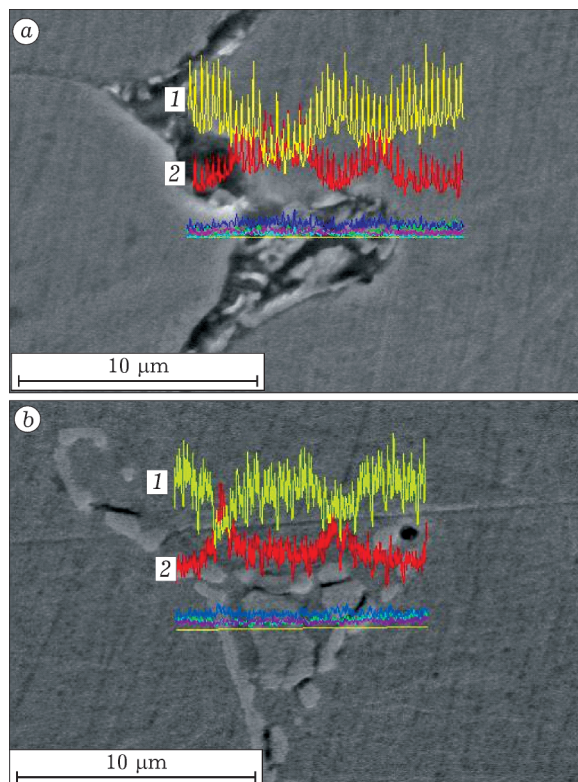


Fig. 10. X-ray mapping of the intergranular corrosion pit on the stainless steel without (a) or with 0.1% (b) SiC nanoparticles: 1- Fe, 2 - Cr.

spectroscopy detection, its morphology and energy spectrum are shown in Figs 9 and 10.

By the line scan spectrum curve, in the case of intergranular corrosion of the region, stainless steel without SiC nanopowder exhibits uneven distribution of chromium, chromium low-loss region of serious matrix, forming a deep pit. Stainless steel with nano-SiC powder, intergranular corrosion minor matrix no significant fall off, do not form pits, indicating that the stainless steel intergranular corrosion resistance and chromium are closely related to the distribution of elements. Therefore, in stainless steel production, to reduce impurities and improve the distribution of chromium in steel, homogeneity of the material can effectively improve the intergranular corrosion resistance.

#### 4. CONCLUSIONS

1. With the addition of nano-SiC powder, the ability of the anti-chemical pitting corrosion and anti-electrochemical pitting corrosion of stainless steel markedly improved.

2. Adding nano-SiC powders can significantly enhance the intergranular corrosion of stainless steel, and intergranular corrosion of stainless steel by metallographic evaluation and the bending resistance exhibit a very good consistency.

3. With the addition of SiC nanopowder, the ferritic precipitates and chromium reduce segregation, so SiC nanopowders can help effectively avoiding the two-phase chromium-depleted zones and areas prone to localised corrosion, such as the emergence of the region.

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