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Effect of the La alloying addition on the antibacterial capability of 316L stainless steel

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ABSTRACT

316L stainless steel is widely used for fashion jewelry but it can carry a large number of bacteria and cause the potential risk of infection since it has no antimicrobial ability. In this paper, La is used as an alloying addition. The antibacterial capability, corrosion resistance and processability of the La-modified 316L are investigated by microscopic observation, thin-film adhering quantitative bacteriostasis, electrochemical measurement and mechanical test. The investigations reveal that the La-containing 316L exhibits the Hormesis effect against *Staphylococcus aureus* ATCC 25923 and *Escherichia coli* DH5α, 0.05 wt.% La stimulates their growth, as La increases, the modified 316L exhibits the improved antibacterial effect. The more amount of La is added, the better antibacterial ability is achieved, and 0.42 wt.% La shows excellent antibacterial efficacy. No more than 0.11 wt.% La addition improves slightly the corrosion resistance in artificial sweat and has no observable impact on the processability of 316L, while a larger La content degrades them. Therefore, the addition of La alone in 316L is difficult to obtain the optimal combination of corrosion resistance, antibacterial capability and processability. In spite of that, 0.15 wt.% La around is inferred to be the trade-off for the best overall performance.

1. Introduction

316L stainless steel is one of the main materials for fashion jewelry but it has no antibacterial efficacy [1]. Since jewelries often carry a large number of bacteria and give rise to the risk of infection [2,3], it is important to improve the 316L's antimicrobial performance. Antibacterial stainless steel has become one research hotspot in biomaterial field and the alloying method is an important approach. So far, most of the work has been focused on Cu-containing stainless steel, by adding 1–5 wt.% copper into stainless steel and taking special heat treatment, ε-Cu phase could precipitate in the matrix [4–7]. When the treated materials contact with bacteria, Cu ions would release from ε-Cu phase and gave play to antibacterial function [8]. The antibacterial effect depended on the antibacterial phase's quantity, shape and size, in order to acquire good antibacterial performance, the precipitated ε-Cu phase should not be lower than 0.5% [9]. On the whole, Cu-containing antibacterial steels had to be kept at 700–900 °C for a long time since the precipitation of ε-Cu phase was controlled by the diffusion mechanism [10,11]. This complicated the technological process and increased production cost, and the long-time preservation at the sensitized interval would degrade the material's corrosion resistance more or less. Silver is an excellent antibacterial agent and it has also been tried for antibacterial stainless steel. Yokota et al. [12] found that silver-containing stainless steel could acquire excellent antibacterial properties by adding vanadium, restricting sulphur content and controlling speed, Liao et al. [13] reported that the microstructure of 304 stainless steel consisted of α + γ + Ag-riched phase, and the modified steel showed excellent antibacterial effect against *Escherichia coli*. Huang et al. [14] also reported that ≥0.2 wt.% Ag in AISI 316L alloy would have excellent antibacterial properties against both *Staphylococcus aureus* and *E. coli*. However, silver is quite prone to form severe segregation since its solubility in stainless steel is very limited, and it will markedly increase the cost.

As is known, the compounds or of rare earth have antibacterial, sterilization and anti-inflammatory effect [15–17], and Cerium has been tried as an antibacterial agent in stainless steel. Jing et al. [18] reported that 0.05–4.5 wt.% Ce-bearing 304 stainless steel could show excellent antibacterial effect with no need for special heat treatment. Wang et al. [19] reported that the bactericidal activity of Cerium-doped TiO_2 film on 304 stainless steel was better than pure TiO_2 film. However, there is no further report about Cerium-bearing stainless steel, and there is no any report about La as an antibacterial agent in stainless steel up till now. Therefore, the effects of La on the antibacterial property, corrosion resistance and processability of 316L stainless steel were investigated in this paper.

2. Experimental

2.1. Materials preparation

30 wt.% La–Fe master alloy was prefabricated with pure La and pure iron by using a WK-vaccum arc furnace, then commercial 316L

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Table 1
The actual amounts of La in the samples, wt.%.

Sample No.	Amount of La
La0	–
La1	0.05
La2	0.11
La3	0.19
La4	0.42

stainless steel strips and La–Fe alloy were used to prepare the testing samples, after the charging materials were melted uniformly, small button ingots were made in water-cooled copper crucible. The actual amounts of La in the ingots were determined by using Thermo ARL Quant' X spectrum analyzer and were listed in Table 1.

The ingots were hot forged into sheets of about 2 mm thick and were solid solution treated at 1050 °C for 30 min. Dics (ϕ25 mm) or square (5×5 mm) specimens were machined from them, polished with 1200# sand papers and cleaned with an ultrasound cleaner.

2.2. Experimental methods

2.2.1. Antibacterial experiment

The samples were sterilized in a 121 °C autoclave for 40 min and then sterilized once again under an ultraviolet sterilamp for 30 min. Bacterial colony of *S. aureus* ATCC 25923 and *E. coli* DH5α (taken from College of life science, Jinan University) was inoculated respectively into a 15 ml nutrient broth (produced by MDBio Inc., which contained peptone 10.0 g/l, NaCl 5.0 g/l and beef extract 5.0 g/l) as the test strain. The broth was shaken in wave bed for 20 h at 37 °C. The suspension of bacteria was diluted to 1×10^6 CFU/ml with a PBS buffer solution (KH_2PO_4 0.27 g/l, Na_2HPO_4 1.42 g/l, NaCl 8 g/l, KCl 0.2 g/l, Twain-20 0.05 ml/l, PH7.4).

Inhibition zone test [20] and thin-film adhering quantitative bacteriostasis test [21] were used to examine antibacterial properties. In inhibition zone test, 500 μl of the diluted suspension was evenly smeared on agar plate, and sterilized disc samples were closely stuck on the surface of the plate respectively. After cultured at 37 °C for 24 h, the inhibition zone was directly observed. In thin-film adhering quantitative bacteriostasis test, 50 μl of the diluent was dropped on each sterilized disc sample. The samples were covered with a sterile thin film for the bacteria to spread over uniformly and kept in a test chamber for 24 h at the constant temperature of 37 °C and in the relative humidity of over 90%. Each sample was then

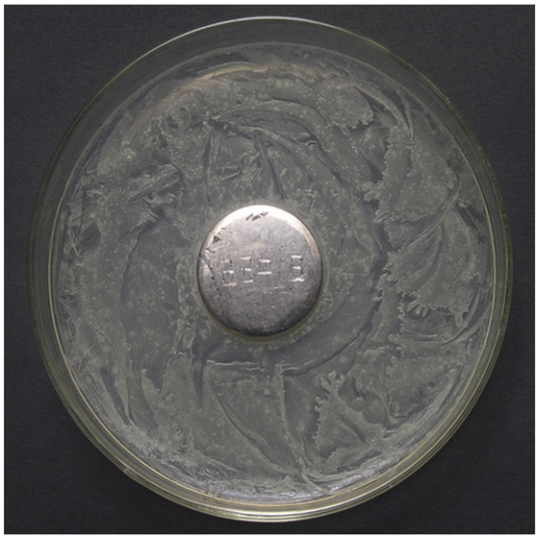

Fig. 1. The inhibition zone of sample La4 against *Staphylococcus aureus*.

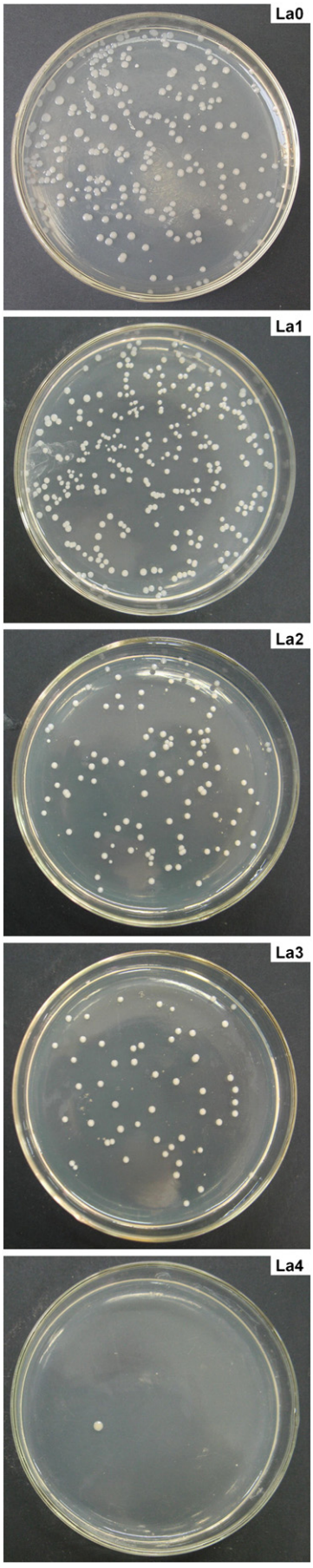

Fig. 2. The antibacterial effect against *Staphylococcus aureus* of each sample.