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# Effect of post-weld heat treatment on microstructure evolution and pitting corrosion behavior of UNS S31803 duplex stainless steel welds

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ABSTRACT

The effect of tungsten inert gas welding and subsequent post-weld heat treatment on the microstructure evolution and pitting corrosion behavior of duplex stainless steel UNS S31803 was investigated. Detailed microstructure examination demonstrates that ferrite presents higher volume fraction and is easier to suffer attack of pitting corrosion than austenite in the welded zone of as-welded metal. After post-weld heat treatment, the volume fraction of austenite in the heat affected zone and weld metal is elevated significantly. The highest pitting corrosion resistance is obtained at 1080 °C with the highest critical pitting temperature and pitting nucleation resistance.



## 1. Introduction

Duplex stainless steels (DSSs) are increasingly used in marine construction, chemical industries and power plants thanks to their attractive combination of mechanical properties, weldability and corrosion resistance in various types of environments [1–6]. For insuring a combination of good corrosion resistance and high strength, DSSs are essential to maintain a ferrite/austenite ratio close to 1:1 [7,8]. However, this phase balance will be disturbed during welding on account of the rapid cooling involved in most weld thermal cycles [7–11].

It is well-known that welding is an inevitable fabrication process for large industrial applications of DSSs. Both in the heat affected zone (HAZ) and weld metal (WM), the microstructure undergoes both rapid heating and cooling cycles which drive excessive ferritization to occur [12]. Furthermore, some unwanted phases including carbide, sigma phase, chi phase, chromium nitride and secondary austenite etc. are prone to form during welding [12,13]. These undesirable excessive ferritization and precipitations can cause a dramatic deterioration of mechanical properties and corrosion resistance of duplex stainless steel welds [14,15]. In order to promote the application of DSSs, considerable efforts have been devoted to gain a better understanding on the influence of metallurgical factors on their weldability and corrosion resistance [7,8,16]. Muthupandi et al. [8] found that the chemical composition of the weld filler material gets a great influence on the austenite content. Kim et al. [7] investigated the effects of solution heat-treatment and shielding gas on the pitting corrosion of hyper duplex stainless steel (HDSS) welds and reported that the pitting resistance of a solution heat-treated HDSS welded with a combination of Ar and $N_2$ as the shielding gas is greatly increased due to an increase of austenite in the WM and HAZ. Lindblom [16] revealed that welding parameters should be adjusted to insure that the overall cooling rates are slow enough to allow adequate austenite formation within the high-temperature region and yet fast enough to avoid precipitations of nitrides in the low-temperature region, and pointed out an optimal cooling time between 1200 and 800 °C within which austenite reformation and precipitations occur for DSSs. Recently, in order to get an optimal phase balance, several studies have focused on post-weld heat treatment (PWHT) on DSSs weld joints [17–19]. Badji et al. [17] investigated the effect of PWHT in the range of 800–1150 °C on microstructure and mechanical properties of welded 2205 duplex stainless steel and found PWHT temperature lower than 1100 °C courts high micro hardness due to the precipitation phenomena in ferrite phase. Young et al. [18] showed that PWHT at 1050 °C for 15 min is able to effectively raise the austenite content and the impact toughness of the joints. Since PWHT can be carried out by means of different technologies such as furnace, laser and induction heating, Ferro et al. [19] investigated the influence of induction and furnace PWHT on corrosion properties of DSS 2205 and found that the induction PWHT brings on significant thermal gradient and different corrosion resistance across

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the thickness of the welded bead. All those researches have shown that PWHT parameters play an important role in microstructure evalution and corrosion resistance of weld joints, but it is not usually practical to carry out PWHT or hot work for the large weldments, especially the pipe joints. Therefore, a special solution treatment technique called on-line solution treatment is recommended in workshop to meet the needs of practical application. With specified temperature and quench conditions, this kind of PWHT technique calls for the PWHT time is as short as possible. However, very few reports shed light on the effect of short-time PWHT on the microstructure evolution and pitting corrosion resistance of DSSs welds, even though it is very important in optimizing the corrosion resistance of the weld joints and helpful in designing a new alloy with excellent weldability.

In the current work, the effect of tungsten inert gas (TIG) welding and subsequent short-time PWHT on microstructure evolution and pitting corrosion behavior of UNS S31803 duplex stainless steel is investigated. The optimum PWHT temperature is determined. Furthermore, the relationship between microstructure evolution and pitting corrosion resistance of single phase in annealed UNS S31803 duplex stainless steel welds is discussed in detail to explain the pitting morphologies evolution in the welded zone.

## 2. Experimental procedure

### 2.1. Materials and heat treatment

The material used in this work was a commercial DSS 2205 (UNS S31803). The alloy was cold rolled into sheets of 1.4 mm in thickness and annealed at 1040 °C for 1 min. The nominal composition of this alloy is shown in Table 1. The welding parameters are listed in Table 2. Single TIG welding procedure was applied to fabricate the joints without filler metal. The PWHT was carried out at 1020, 1050, 1080 and 1100 °C, respectively in a muffle furnace in atmosphere without protecting gas. In order to simulate the on-line solution treatment conditions, the muffle furnace was heated to the setting temperature, and then the weld joints were put into it and held for 1.5 min at the setting temperature. After that, the joints were taken out and quenched in water. These heat treatments were performed in the "precipitation-free" temperature range. The WM, HAZ and base metal (BM) were included in the specimens, which were cut from the plates with a dimension of $10 \times 10$ mm for electrochemical tests and microscopy.

### 2.2. Microstructure characterization

To observe the optical microstructures of the WM, HAZ, and BM in the welded alloy, the specimens were ground successively to 2000 grit, polished with diamond paste to 0.25 μm, and then electrochemically etched in a 30 wt.% KOH solution, which revealed the microstructure with austenite phase light and ferrite phase dark. The volume fraction of ferrite and austenite was evaluated carefully by a CARL ZEISS optical microscope equipped with a KS400 quantitative metallographical analysis system. The final value was the average of at least 12 measurements, each at different zones of the samples. Oxalic acid solution was used to reveal the presence of secondary phases [10]. The chemical compositions of austenite and ferrite phase and the pit morphology were measured using energy dispersive X-ray spectroscopy (EDS) linked to a scanning electron microscopy (SEM, FEI Quarter 400) with a Robinson backscattered electron detector. Each value of the element distribution was an average of more than 10 measurements. Furthermore, a JEOLJEM2100F transmission electron microscope (TEM) was used for identification of the precipitates.

**Table 2**
Tungsten inert gas welding parameters.

| | |
|---|---|
| Welding current (A) | 120 |
| Welding voltage (V) | 12 |
| Welding speed (cm/min) | 30 |
| Shielding gas flow: Ar (L/min) | 15 |
| Backing gas flow: Ar (L/min) | 5 |

### 2.3. Electrochemical testing

All measurements were carried out with a potentiostat PARSTAT 2273 in a three electrode cell. A platinum foil and a saturated calomel electrode (SCE) were used as the counter and reference electrodes, respectively. All potentials quoted in this paper refer to SCE. The test solution, 1 mol/L NaCl, was made up of analytical grade reagent and distilled water. The specimens acting as working electrodes were mounted in epoxy resin. In order to avoid crevice corrosion, the interface between specimen and resin was sealed with special silica gel sealant and dried in air [20]. The exposed electrode surface area was 100 $mm^2$. Potentiodynamic polarization tests were carried out in 1 mol/L NaCl solution at a scanning rate of 0.33 mV/s from −800 mV (SCE) at 60 °C (above or near CPT) to the potential at which the current indicated that stable pitting or transpassivity had occurred. Potentiostatic measurements were performed to obtain the critical pitting temperature (CPT) with an anodic potential of 750 mV (SCE) until stable pitting occurred. The electrolyte temperature was elevated continuously at a rate of 1 °C/min. The CPT was defined as the temperature at which the current density reached 100 μA/$cm^2$. The electrolyte was bubbled with pure nitrogen gas ($N_2$) to get rid of the dissolved oxygen gas ($O_2$) throughout the test. Any crevice corrosion observed on the specimens after testing meant that the test results were invalid and had to be discarded.

## 3. Results and discussion

### 3.1. Microstructure of as-welded metal

Fig. 1(a) shows the optical microstructure of the base metal consisted of austenite and ferrite. Austenite phase is shown as white, while the gray region is ferrite phase. The island-like austenite phase is embedded in the continuous ferrite matrix and elongated along the rolling direction without apparent secondary phase precipitation.

Fig. 1(b and c) present the optical microstructure of the WM. The micrographs reveal that the edge structure of the WM (near the fusion line) consists of columnar ferrite grains because of the epitaxial growth, while in the centre of the WM, equiaxed ferrite grains are found. The microstructures of the specimens in the welded zones consist of ferrite grains decorated with grain boundary austenite (GBA), Widmänstten-type austenite (WA) nucleared from GBA and intragranular austenite (IGA). All three kinds of aus-

**Table 1**
Chemical composition of UNS S31803 duplex stainless steel.

| Element | C | Si | Mn | P | S | Cr | Ni | Mo | N | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| Wt.% | 0.021 | 0.46 | 1.52 | 0.008 | 0.001 | 22.36 | 5.72 | 3.02 | 0.17 | Bal |