



Microstructure and corrosion behavior of S32101 stainless steel underwater dry and wet welded joints

Kun Sun^{a,b}, Min Zeng^{a,b}, Yonghua Shi^{a,b,*}, Yu Hu^{a,b}, Xiaoqin Shen^{a,b}

^a School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, China

^b Engineering Research Center for Special Welding Technology and Equipment of Guangdong Province, Guangzhou 510640, China

ARTICLE INFO

Keywords:

Underwater welding
Flux-cored arc welding
Microstructure
Localized corrosion
Duplex stainless steel

ABSTRACT

This work focused on the microstructures, secondary phase precipitation and susceptibility to localized corrosion of UNS S32101 duplex stainless-steel welded joints that were welded using underwater dry and wet flux-cored arc welding (FCAW-136). The size and proportion of the austenite phases of the underwater dry welded joints were larger than those of the underwater wet welded joints under the same heat input conditions. In addition, the weld metal exhibited a better resistance to localized corrosion than the heat-affected zone. The high-temperature heat affected zones of the welded joints prepared using underwater dry welding showed improved performance compared with those prepared using underwater wet welding under the same heat input because of the reduced precipitation of chromium-rich nitrides. The resistance to localized corrosion of the low-temperature heat affected zone increased with increasing heat input for the underwater wet welded joints, whereas a reverse trend was observed for the low-temperature heat affected zone of the underwater dry welded joints.

1. Introduction

Underwater welding has become an essential mean to repair and maintain marine constructions in the development and utilization of marine resources. Underwater arc welding can be further classified into wet welding, dry welding or underwater local-cavity dry welding. The weld is exposed to a wet environment during wet welding. In contrast, dry welding is performed in a chamber that is sealed around the structure to be welded, and the chamber is filled with gas at the prevailing pressure. Local-cavity dry welding applies a local cavity to protect the weld arc from water during welding. Because of the different welding environments, there are large quality differences between wet and dry welded joints.

Duplex stainless steels (DSSs) are composed of nearly equal fractions of ferrite (α) and austenite (γ) phases. Garzón and Ramirez (2006) reported that the balanced ferritic–austenitic fine-grain microstructure and high proportion of alloying elements, which improve the corrosion resistance are two of the most important factors leading to the excellent combination of mechanical and corrosion-resistance properties of these steels. Recently, power plants, desalination facilities, off-shore petroleum facilities, and chemical plants have shown an increasing interest in DSSs, because of their high resistance to corrosion and excellent mechanical properties.

During fusion welding, welding wire melt as a weld metal and DSS

base metal (BM) undergo a series of thermal cycles. During the welding of DSSs, solidification of the weld metal occurs and the solid high-temperature heat-affected zone (HTHAZ) is fully ferritic; then, austenite begins to form below the solidus temperature during subsequent cooling. It is difficult to maintain equal fractions of α - and γ -phases and a suitable grain size. The ratio of γ/α of low-temperature HAZs changes because the annealing under is performed at a lower temperature. The microstructure of the weld metal depends on the thermal cycle, chemical composition of the welding wire and shielding gas. Nevertheless, the heat input and cooling rate have a significant effect on the microstructure and harmful secondary phases of the HAZ. The degree of sensitization (DOS) of S32101 is determined by the chromium (Cr)-depleted zone that is adjacent to harmful secondary phases, such as carbides, nitrides, and sigma (σ). Deng et al. (2010) studied the effects of thermal aging on the intergranular corrosion of LDX2101 (S32101) and reported that, compared with other DSSs (SAF2205 and SAF2507), the kinetics of σ phase precipitation of LDX2101 was much slower because of the relatively lower Cr and Mo contents. Duprez et al. (2001) revealed that Mo was the main element controlling the sigma precipitation because the σ phase had a high Cr and Mo contents. The lower concentration of Mo in S32101 suggests a lower likelihood for the precipitation of σ phases. Chromium-rich nitrides are the main harmful secondary phases that are likely to nucleate and grow in the α – α and α – γ grain boundaries and in the inter- α grains. Omura et al. (2000)

* Corresponding author at: School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, China.
E-mail address: yhuashi@scut.edu.cn (Y. Shi).

investigated the effect of the cooling rate on the precipitation of Cr nitrides within laser welded DSS. They confirmed that the CrN/(CrN + Cr₂N) fraction increases in the HTHAZ of 2205 welded joints upon increasing the cooling rate. Recently, many researchers have performed studies on underwater welding. Zhai et al. (2017) simulated local dry underwater tungsten inert gas welding with a flux-cored wire and analyzed high-speed photographs of the metal transfer process. Labanowski et al. (2012) assessed the weldability of GMA local cavity welding of duplex stainless steel at 0.5 m water depth condition and in the air. They confirmed the good weldability at underwater conditions of duplex stainless with the use of GMA local cavity method. These studies were focused on welding duplex stainless steels in underwater local dry welding method. Akselsen et al. (2009) assessed the weldability of duplex stainless steel under hyperbaric conditions. Hu et al. (2017) estimated the effect of ambient pressure on the microstructure, pitting corrosion resistance and impact toughness of the weld metal. These studies were focused on welding duplex stainless steels in underwater dry welding method. Guo et al. (2015) studied the effects of arc voltage on the stability of the underwater wet flux-cored arc welding (FCAW-S 114) process. Chen et al. (2018) studied the effects of flow rate and direction on the metal transfer mode and molten pool shape in the underwater wet flux-cored arc welding (FCAW) process. Labanowski et al. (2016) assessed the weldability of duplex stainless steel in underwater conditions and determined the susceptibility to form cold cracks in the ferritic-austenitic 2205 duplex stainless steel welded under water with the use coated electrodes. Shi et al. (2017) studied how pores perform in underwater wet flux-cored arc welding of S32101 duplex stainless steel welds, and discussed the relationship between porosity and austenite morphology in microstructures. Kralj et al. (2009) evidenced that if adequate welding parameters and filler materials are used good quality of underwater wet welds on duplex steel is possible to achieve. These studies were focused on welding duplex stainless steels in underwater wet welding method.

Although research has been conducted on the microstructure and corrosion resistance of S32101 welded joints, no systematic build-up has been proposed on the effects of different heat inputs on the DOS and microstructure in S32101 underwater welded joints. The differences between the microstructure, precipitation of chromium-rich nitrides, and corrosion properties of underwater dry welded joints and wet welded joints remain unclear. In this study, S32101 was surface welded by underwater dry flux-cored arc welding (FCAW) and wet FCAW. A double-loop electrochemical potentiokinetic reactivation (DL-EPR) test was used to investigate the DOS of each joint. The aim of this work was to contrast the corrosion behavior of underwater dry and wet welded joints prepared using different heat inputs and to optimize underwater processing by selecting suitable welding process parameters to improve the corrosion resistance of the welded joints.

2. Experimental procedure

The chemical compositions of the BM S32101 DSS and ER2209 flux-cored wire filler metal are listed in Table 1. As shown in Figs. 1 and 2, underwater FCAW experiments were conducted in a hyperbaric chamber containing an automatic underwater welding system. The system comprised a high-pressure chamber, a welding power source, a three-dimensional motion platform and other auxiliary equipment. Before welding, compressed air was pressurized into the chamber to simulate the pressure caused by water depth. A pressure of 0.2-MPa

pressure was used to simulate 20 m of water depth. The S32101 steel plates had dimensions of 300.0 mm × 100.0 mm × 6.0 mm. UNS S32101 DSS was welded by underwater dry and wet flux-cored arc welding (FCAW-136). The diameter of the welding wire was 1.2 mm, and pure CO₂ was used as the shielding gas. During the underwater welding process, the gas flow was 25–30 l/min. The welding experiments were performed at water depths of 20 m.

Kou (2003) reported that, for gas metal arc welding experiments, the required heat input can be calculated using the following equation:

$$q = \eta UI/v \quad (1)$$

where q is the heat input, I is the current (A), U is the voltage (V), v is the welding speed (mm s⁻¹), and η is the arc efficiency for gas metal-arc welding ($\eta = 0.85$). The welding experiments were performed using underwater dry welding (UDW) and underwater wet welding (UWW). During UDW, no water was present in the hyperbaric chamber whereas, during UWW, water was used to simulate an UWW environment. The underwater FCAW process parameters used in the experiments are listed in Table 2.

Optical microscopy (OM) and scanning electron microscopy (SEM LEO1530VP) were used to examine the microstructural details. The welded joints were etched electrolytically in 30 wt.% KOH solution at 2 V for 15 s to examine the microstructures of the weld metal (WM), HAZ, and BM. To determine the volume fractions of the α and γ phases, Beraha's etchant (60 ml H₂O + 30 ml HCl + 1 g K₂S₂O₅) was applied to reveal γ (the light phase) and α (the dark phase). According to ASTM E1245-03 (2016) standard, the images were analyzed using Image Pro software. It was difficult to identify chromium-rich nitride precipitates in the welded joints after electrolytic etching in the 30 wt.% KOH solution and Beraha's etchant. Therefore, oxalic acid was used to verify the precipitation of chromium-rich nitrides. Energy-dispersive spectroscopy (EDS) was used to determine the chemical compositions of the α and γ phases, and transmission electron microscopy (TEM) was used to identify the precipitates. TEM thin foils were prepared by jet polishing (Struers TenuPol-5) in a mixture of 10% perchloric acid and 90% methyl alcohol at 253 K and 20 V.

According to BS EN ISO 12732:2006 (2006), the DL-EPR test is independent of the surface finishing and provides a quantitative value of the degree of sensitization. Thus, during recent decades, the DL-EPR test has been a popular method for evaluating the DOS resistance. In this investigation, DL-EPR tests were conducted on S32101 DSS welded joints.

DL-EPR measurements were conducted using a potentiostat (CHI660C), which consisted of three electrodes. The counter and reference electrodes were a platinum and a saturated calomel electrode (SCE), respectively. The welded joint specimens served as the working electrodes; they were embedded in cold-curing epoxy resin, and their edges were sealed with the resin. Before each experiment, the specimens were ground to 2000 grit using SiC paper, polished with diamond paste, cleaned with alcohol, rinsed with distilled water and dried in hot air. The specimens consisted of a lower-temperature HAZ (LTHAZ), WM, welded zone (WM + HAZ) and BM, as shown in Fig. 3. After the DL-EPR tests, the current density of each specimen was calculated to generate DL-EPR curves and determine the ratios of the peak reaction current (I_r) to peak activation current (I_a). According to BS EN ISO 12732:2006, (2006), although a standard test solution (0.5 M sulfuric acid (H₂SO₄) + 0.01 M potassium thiocyanate (KSCN)) can be used for austenite stainless steels (ASSs), a more aggressive solution is required

Table 1
Chemical compositions of base and filler materials (mass percent, %).

	C	Si	Mn	P	S	Cr	Ni	Co	Mo	Cu	N	Fe
UNS S32101	0.019	0.6	4.8	0.023	0.001	21.6	1.6	0.033	0.17	0.21	0.2	Bal.
ER2209	0.03	0.45	1.22	0.024	0.003	22.52	8.73	–	3.21	0.15	0.14	Bal.

Download English Version:

<https://daneshyari.com/en/article/7176403>

Download Persian Version:

<https://daneshyari.com/article/7176403>

[Daneshyari.com](https://daneshyari.com)