A review on arc welding of Super Duplex Stainless Steel (SDSS) 2507

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KEYWORDS

SDSS,
Corrosion resistance,
Arc welding,
Thin sheet.

ABSTRACT

Super Duplex Stainless Steels (SDSS) are playing an important role in mechanical, marine, gas industries and power plant. Welding is an important joining process involved in the construction of industrial structures. Selection of the welding method is a difficult task because the imbalance of austenite / ferrite ratio results in solidification cracking, reduce corrosion resistance and reduced ductility. Arc welding process like GTAW, GMAW and PAW are available to join the SDSS economically. The primary objective of this paper is to compare various arc welding processes and its welding parameters (welding speed, welding current, welding voltage etc.) for the joints of a thin sheet of SDSS 2507. Effects of SDSS alloying elements (Cr, Mo, Ni and N) on intermetallic phases is also discussed. This study can help to find out the best arc welding process and their welding parameter on phase balance to join the SDSS 2507.

1. Introduction

Since the starting of the 1990 superduplex stainless steels are playing an important role in the various industries. However, the practical application of SDSS involves various manufacturing process including welding [1]. SDSS has 50% of Body-Centered Cubic (BCC) ferrite (α) and 50% Face-Centered Cubic (FCC) austenite (ϒ) contents [2-3]. The Thermal conductivity of SDSS is high, low thermal expansion and excellent corrosion resistance. These properties give a definite design advantage over other stainless steel [4-5]. From the Table 1, three major Element separate SDSS from duplex stainless steel are Nickel (Ni), molybdenum (Mo), and chromium (Cr) have weight percentage is 7.423%, 3.102% and 25.485%. Greater the chromium percentage increases the corrosion resistance. From Table 2 yield point is 550 MPa, and tensile strength is 900 MPa shows excellent mechanical strength and operating temperature of SDSS 2507 is -40°c to 300^{0}c [6-7]. Joining of SDSS 2507 material is necessary to fulfil demand.

There are many welding processes are available to join the SDSS 2507 to fulfil the desire application [8]. Classification of various arc

Table 1
Chemical compositions of SDSS 2507 [6].

Elements	% by weights	Elements	% by weights
C	0.019	Mo	3.102
Si	0.548	Cu	0.173
Mn	0.630	Co	0.070
S	0.004	Ti	0.023
P	0.028	V	0.065
Cr	25.485	Fe	62.329
Ni	7.423	----	----

Table 2
Mechanical properties of SDSS 2507 [7].

Yield Point (Min.) (MPa)	Tensile strength (MPa)	Elongation (%) (Max.)	Hardness (HRC)
550	800-1000	25	32

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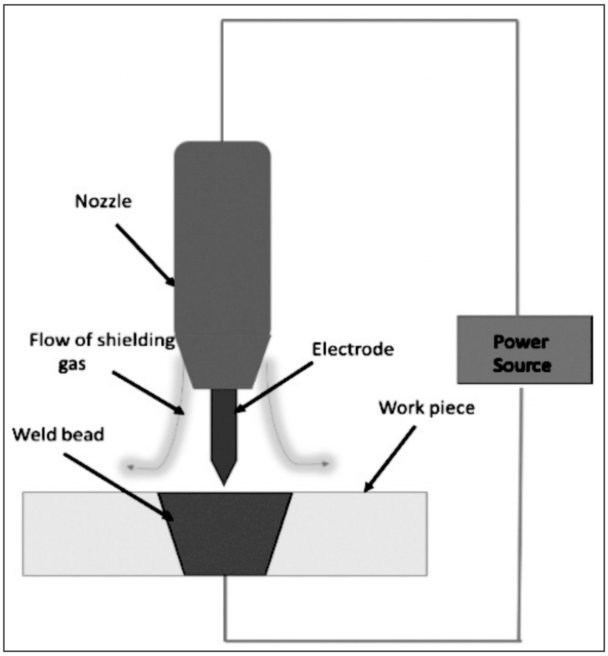

Fig. 1. Welding process for joining SDSS materials.

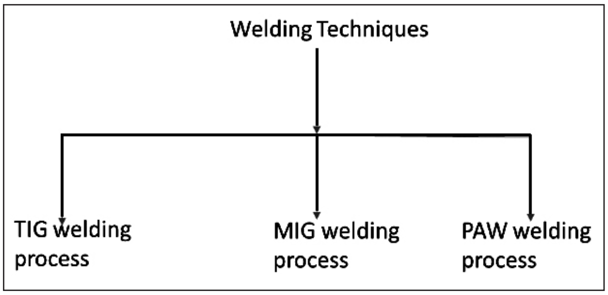

Fig. 2. GTAW welding process.

welding process is in fig. 1. literature on the listed arc welding is discussed in upcoming sections.

1.1 Gas Tungsten Arc Welding (GTAW) process

Gas Tungsten Arc Welding (GTAW) process is also known as Tungsten Inert Gas (TIG) welding, in this welding process, a non-consumable electrode is used as shown in fig.2. Filler metal can be used to make the weld if necessary. GTAW is suitable to weld titanium alloy, aluminium, nickel alloys and stainless-steel family. It is a low-cost welding process [8-9]. In TIG welding a shielding gas (Ar, Co_2 etc.) is used to protect the molten pool from contamination [10]. GTAW is used to weld SDSS because of high-quality weld deposited and penetration depth and the productivity can be increased by the use of Activated flux TIG (A-TIG) welding [11]. Korra et al. analysed the effect of activated GTAW parameters on the depth of penetration of SDSS 2507 using response surface methodology. Design matrices are generated using Analysis of Variance (ANOVA) and Design of Experiments (DOEs). For obtaining higher penetration the torch speed must be slower and the current should be higher.

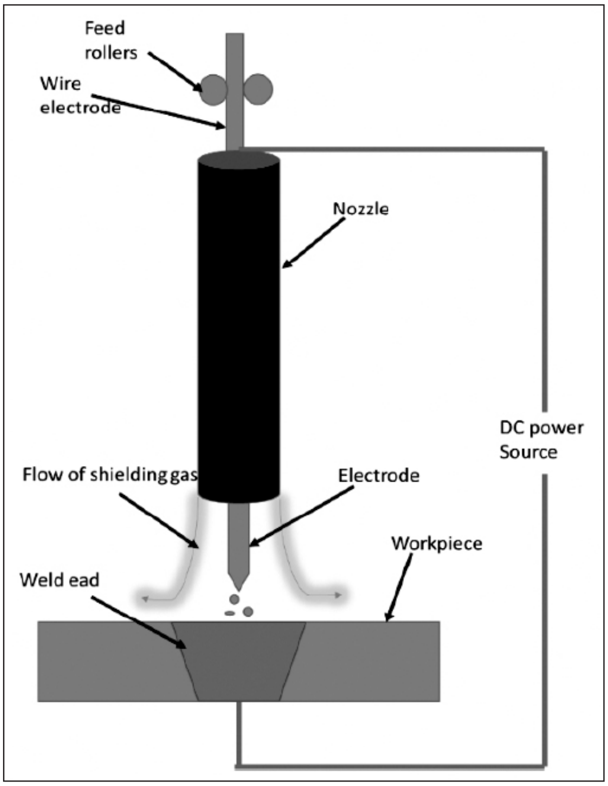

Fig. 3. Gas metal arc welding process.

Welding current has more effect on the depth of penetration with TIG welding as compared to another welding process [6]. Hosseini et al. measured the nitrogen loss with wavelength dispersive X-ray spectrometry (WDXS) under the TIG welding of SDSS. Microstructure for each welding pass up to four passes is recorded by WDXS. For each pass, nitrogen quantity is measured. Nitrogen quantity was reduced for each pass [22]. Verma et. al, (2016) have analysed the microstructure, corrosion resistance and mechanical properties of SDSS. Activated flux TIG welding was used for higher production without distortion. For proper phase balance heat input should be in the range of 1.5kJ/mm [23].

1.2 Gas Metal Arc Welding (GMAW) process

Gas Metal Arc Welding (GMAW) process is also known as Metal Inert Gas (MIG) welding (as shown in fig. 3). In this welding process, a consumable electrode wire is used. Shielding gas is provided to protect the weld from the environmental contaminations [12]. This welding process is preferred for its faster welding speed as compared to other arc welding process. GMAW can be transfer metals by globular, short-circuiting and by spray transfer modes. A globular transfer can use the droplet size bigger than the wire diameter.

Due to spatter, the globular transfer is only for insignificant parts. Spray transfer, the size of the droplet is smaller than the wire diameter. It is an extremely stable effective process and is commonly used in welding thick steel plates and aluminium part. The short-circuiting transfer is a superior transfer mode the liquid droplet on the wire tip creates direct contact with the workpiece. It needs low heat input and hence is usually used in welding thin sheets [13]. So short-circuiting metal transfer is efficient for a thin sheet of SDSS. The benefit of welding SDSS using GMAW is adding the ferrite and austenite contains using cold wire feed [14]. Valiente Bermejo et al. performed the experiments on SDSS 2507 using multi-pass GMAW and flux-cored arc welding and analysed various results. The reliability and for the temperature measurement thermocouple was inserted into the weld pool by backside drilling of the workpiece. In this paper, Ferrite contains were measured by magnetic permeability [1]. Bermejo et al. studied the effect of shielding gas on the welding performance and properties of SDSS. Shielding gas containing (70% ar+30% He) mixture gives the best results in the microstructure. Pure argon shielding gas shows poor arc fluidity and unstable arc. The mixture of argon and 2% CO_2 shows under-fill and porosity in the weld profile. For all shielding gas, balance microstructure was found in the weld. Corrosion resistance is excellent with shielding gas composition 30% Ar, 67.7% He, 0.5% Co_2, 1.8% N_2 was used [10].

1.3 Plasma Arc Welding (PAW) process

In PAW the electric arc is generated between a tungsten electrode and workpiece shown in fig. 4 [15-17]. PAW has smaller Heat Affected Zone (HAZ) because of high penetration power and high welding speed than conventional arc [18]. For these reasons, PAW is a useful technique for welding SDSS steels. PAW process has a lot of advantages over conventional TIG in terms of productivity and penetration depth [19-21]. Taban analysed the microstructure and toughness of the SDSS using PAW. Low heat input provided high ferrite contains in SDSS weld zone. The toughness of the SDSS was increased by increasing heat input. For welding of SDSS, PAW needs heat input in the range of 0.5 kJ/mm to 2kJ/mm in a controlled environment [15]. Migiakis et al. studied the effect of nitrogen and nickel on the microstructure of SDSS weldment. Nitrogen addition in the shielding gas increased the tensile strength of the weld zone. Consuming 2% N_2 in the shielding gas, 50% austenite and 50 % ferrite was obtained in the microstructure of weld zone [16].

2. Discussions

2.1 Phase balance

In SDSS, it remains suggested to maintain ferrite to austenite equilibrium. Throughout welding,

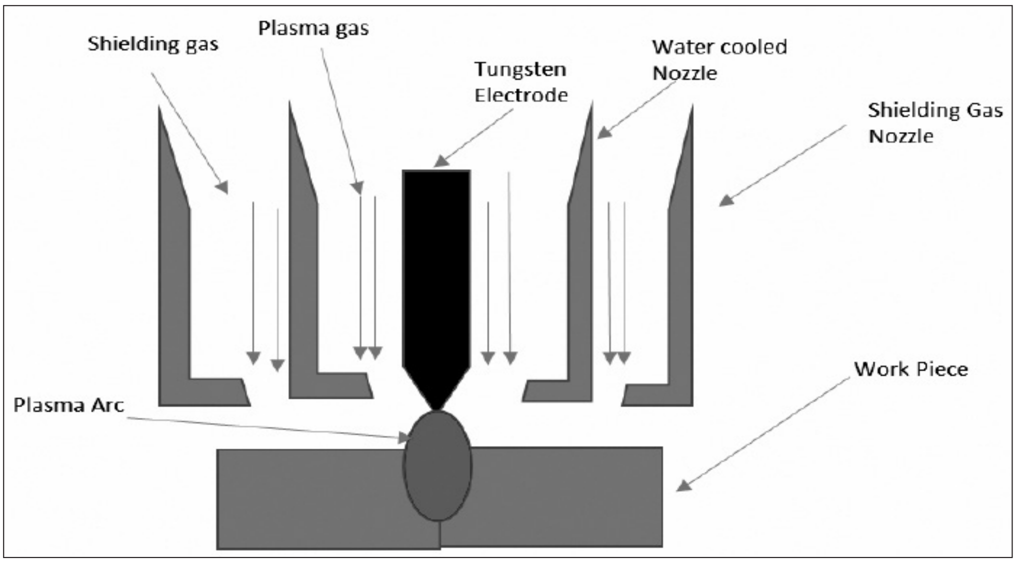

Fig. 4. Plasma arc welding process [20].

this equilibrium is concerned due to ferritization at high temperatures related to welding process. More ferrite contents are not desired as it creates the material lying to pitting occurrence. The cooling rate and heat input in welding are significant they switch ferrite to austenite change [24-26]. The high heat input helps precipitation of sigma phase, carbides and nitrides in HAZ. Slow cooling makes more austenite however at the same time, it may reason precipitation of intermetallic phases as represented in Table 3. Therefore, the cooling rate is preserved low to keep phase balance but high enough to avoid the intermetallic phase formation[27-28]. Filler material with 4.7% Nickel (Ni) is a good choice based on life and economy of the weldments for corrosive environments [29].

The main alloying elements in SDSS are Nickel (Ni), Molybdenum (Mo), Chromium (Cr), Nitrogen (N), Copper (Cu), and Manganese (Mn) are also discussed here [30].

2.11 Chromium (Cr)

Cr performs as a ferrite additive [31]. The main purpose of Chromium is to increases the corrosion resistance by forming a protecting layer of oxy-hydroxide. But there is a limitation on the addition of chromium to SDSS because increasing Cr contents from the harmful intermetallic phases in SDSS [32].

The chromium equivalent in SDSS is

$$Cr_{eq} = 0.7\ \%\ Nb + \%\ Mo + \ \%\ Cr$$

2.12 Molybdenum (Mo)

Molybdenum is a ferrite additive [31]. It creates oxy-hydroxide layer or molybdate ion to protect SDSS from the crevice and pitting corrosion attack. But high molybdenum contents may lead to the formation of harmful sigma and chi phase at high temperatures [33].

2.13 Nickel (Ni)

Ni act as an austenite preservative. The function of Nickel is to regulate phase balance and separate the element. To maintain a balance between austenite and ferrite, the austenite additive and ferrite additive have to be added in a proper amount [33]. The Ni equivalent is given by

$$Ni_{eq} = 20 \cdot \%N + 0.25 \cdot \%Cu + 35 \cdot \%C + \%\ Ni$$

Table 3
The several intermetallic phases that can occur in SDSS [30].

Intermetallic Phases	Chemical formula	Temperature range (^{0}C)
Sigma	FeCrMo	600-1000
Chi	$Fe_{36}Cr_{12}Mo_{10}$	700-900
R	Fe-Cr-Mo	550-800
Pie	$Fe_7Mo_{13}N_4$	550-600
Prime alpha phase	Fe-Cr	475
Nitrides	CrN/Cr_2N	700-900
Carbides	$M_7C_3/M_{23}C_6$	550-650

The high nickel content is needed for corrosion resistance but, enhances the prime-α phase formation in ferrite which causes brittleness of the material [34].

2.14 Nitrogen (N)

Nitrogen act as an austenite additive. It increases austenite content, strengthand pitting resistance of SDSS. Nitrogen has positive effects on corrosion resistance of SDSS. N stays the precipitation of intermetallic phases. At the same time, the high nitrogen content causes precipitation of nitrides [35-37].

2.2 Effects of intermetallic-phases on mechanical properties of SDSS

2.21 Toughness

Toughness is brutally affected by the formation of intermetallic phases and compounds. In all studies, it is found that even a small volume fraction of Sigma (σ) phase causes a drastic reduction in toughness value [31,38]. The minimum allowable Sigma phase content in SDSS is 8% [39]. Effect of R-phase on impact toughness of SDSS found that at 600°C, R-phase was formed and later it was transformed to sigma phase. The reduction in toughness with R-phase was severe [40].

2.22 Hardness

In SDSS increase in sigma (σ) phase, hardness increases in a parabolic manner [41]. Toughness is more sensitive than hardness to belongings of

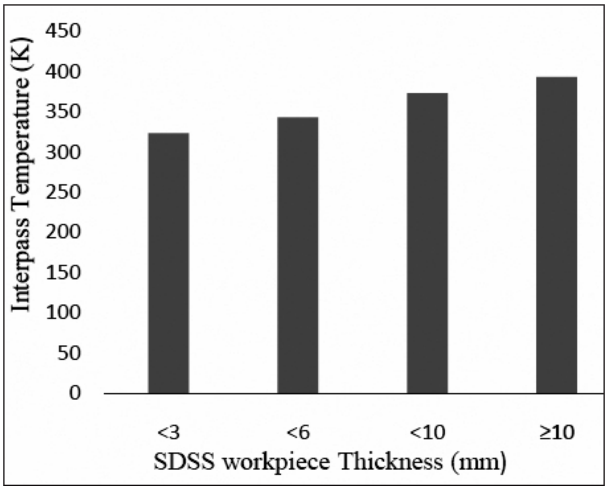

Fig. 5. Interpass temperature with workpiece thickness of SDSS [23].

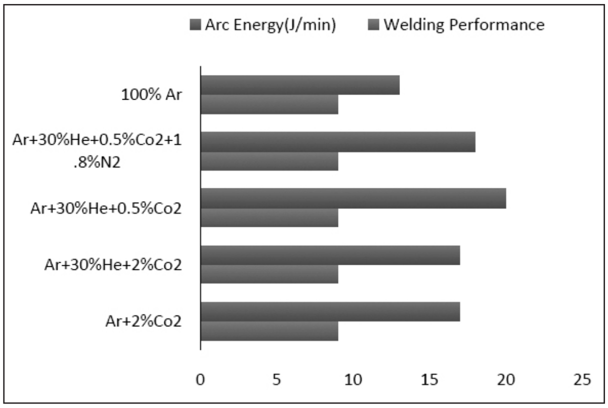

Fig. 6. Comparison of shielding gas and welding performance [10].

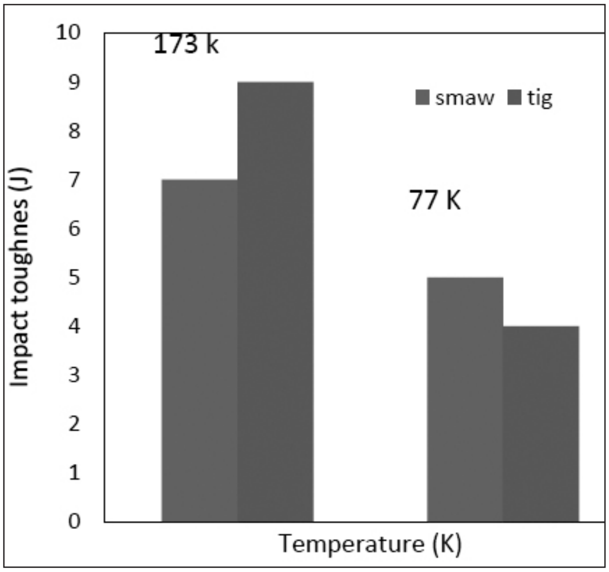

Fig. 7. Impact toughness of SDSS with SMAW and TIG welding process [2].

low volume percentage of intermetallic phases [42]. Hardness increases with an increase in ageing time for all temperatures [45].

2.23 Tensile strength

The Sigma (σ) phase development effects increase in tensile and yield strength between temperatures (750–850^{o}C). Beyond 900^{0}C effect of sigma, formation is insignificant [43]. Internal brittle micro-cracking of sigma (σ) phase causes a decrease in strength beyond general material yield level known as low-stress failures [44].

Fig. 5 shows the Interpass temperature with the various thickness of SDSS. For less than 3mm thickness of SDSS, inter-pass temperature is 323 K.

The welding performance by applying five different shielding gases in the weld zone. All shielding gas shows better performance with SDSS except 100% argon. Arc energy is higher with 69.5 % Ar, 30% He, 0.5% Co_2 as shielding gas and minimum arc energy when shielding gas was only Argon shown in Fig. 6 [10].

Fig. 7 shows the effect of impact toughness on SDSS with Shielded Metal Arc Welding (SMAW) and TIG welding process. When the temperature is increasing the impact, toughness is increasing more for TIG welding.

3. Conclusions

Super duplex stainless steels have equal austenite and ferrite contains, due to excellent corrosion resistance it is used in the mechanical, marine and gas industries. In this paper after studying many researcher's analysis and results about the arc welding of SDSS2507 following conclusion are made -

- GTAW is used to weld SDSS because of high-quality weld deposited and penetration depth and the productivity can be increased by the use of activated flux tungsten inert gas welding.
- For joining SDSS using PAW has greater productivity, penetration depth, and concentrated energy as compare to TIG.
- To maintain the phase balance of SDSS, chromium (Cr) and Nickel (Ni) contains should be balance because Chromium performs as a ferrite additive and Nickel performs as an Austenite additive.

Intermetallic phases affect mechanical properties like toughness, hardness and tensile strength. Sigma (σ) phase causes a drastic reduction in toughness value and increases the hardness value.

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