EFFECT OF HEAT INPUT AND SHIELDING GAS MIXTURE ON THE MICROSTRUCTURE OF SUPER DUPLEX STAINLESS STEEL WELDS

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INTRODUCTION

Duplex stainless steels find ever-increasing applications in chemicai, off-shore, paper/pulp and fertilizer industries owing to their excellent combination of mechanical and corrosion properties [1-3]. More demanding situations prefer super duplex stainless steels, which have higher pitting resistance equivalence [4]. Even though many of the conventional welding processes are employed for joining of these high-performance materials, still the industries face the problem of achieving the desired properties - especially the corrosion resistance, in the resultant weldments [5-7]. Welding upsets the ferrite-austenite microstructural balance in the weld metal and in the high temperature heat affected zone. More so, industrially different gas/gas mixture combinations are employed for achieving the desired properties [8-10]. In the current work an attempt has been to study the effect of different welding processes on weld metal microstructure in the super duplex stainless steel grade SAF 2507.

EXPERIMENTAL

SAF 2507 grade super duplex stainless steel with a chemical composition given in Table 1 has been used in the present investigation. Samples of size 50 x 200 x 15 mm were cut from plates. Bead on plate welds (stringer type) were made with single pass by different welding processes. The different welding processes and the process parameters employed are presented in Table 2.

The resultant weldments were subjected to metallographic examination by adopting the conventional polishing technique and subsequently etched electrolyticaily using a 40% KOH solution under 10 V. The representative features from each sample were photo micrographed.

Bulk hardness measurements (in the weld, HAZ and base metal regions) were made using a Zwick hardness tester under a load of 10 N. Micro hardness measurements were also performed under a load of 1 N to check the hardness values of ferrite and austenite regions in the samples.

RESULTS AND DISCUSSION

Fig. 1 shows the microstructure of base material, revealing the presence of near equal amounts of austenite and ferrite. The ferrite regions are seen as dark etched regions in the micrograph. The microstructure of the weld metal (Fig. 2), produced by shielded metal arc welding process with stringer bead technique, shows the morphological features of austenite and ferrite. Because of the higher cooling rates associated with welding, which control the solidification and subsequent solid state transformation in the SDSS weld regions, a distinctly different morphological microstructure is obtained in these welds when compared to the base material. The microstructure depicts the characteristic columnar grain structure of weld metals, with the austenite being manifested in three different forms viz., grain boundary austenite, Widmaanstatten austenite and intragranular austenite, in the matrix of ferrite. Though the rapid cooling rates associated with welding should result in higher ferrite content in

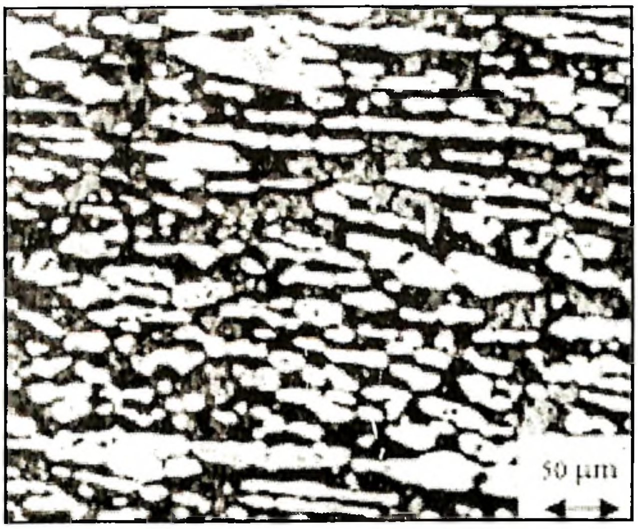

Fig. 1 : Microstructure of SDSS base material (dark etched region – ferrite)

Fig. 2 : Microstructure of SMAW weld metal showing the morphological features of austenite

Fig. 3 : Microstructure of GTA welded sample (argon shielding) (note-predominantly a ferritic structure)

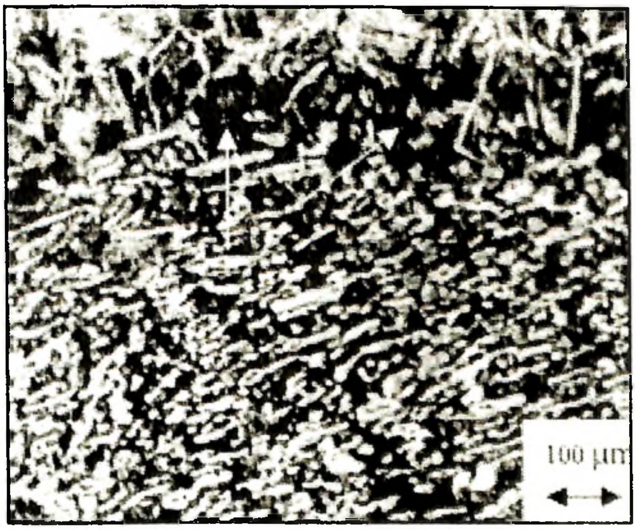

Fig. 4 : Microstructure of SMA weld HAZ

Table 1 : Chemical Composition of Super Duplex Stainless Steel (SAF 2507)

Element	C	S	P	Si	Mn	Cr	Ni	Mo	N
				Weight %					
Weight %	0.02	0.02	0.03	0.60	1.60	25.30	6.85	3.35	0.18

SDSS, nearly equal amounts of ferrite and austenite could be noticed in this weld metal due to the fact that the SMA welding electrodes used for joining of duplex stainless steels are usually enriched with 4-5 % more nickel than in the parent material.

Fig. 3, which depicts the microstructure of autogenous GTA weld with argon shielding, substantiates the above fact that the effect of composition plays an important role in controlling the ferrite-austenite ratio of SDSS weld metal. With the GTA welding under a relatively low heat input conditions (1.13 $kJ.mm^{-1}$), the cooling rates are faster and hence the morphology of austenite in the weld metal is also altered: (a) grain boundary austenite - not so thick as in the earlier case - and occasionally discontinuous and (b) predominantly intragranular austenite. It has been reported that the sequence of formation of austenite from ferrite on cooling is as follows : (a) grain boundary austenite - allotriomorphs - formed at higher temperature (close to solvus), (b) Widmanstatten austenite - in the intermediate conditions and (c) intragranular austenite - generally around and below 700°C [10]. In this particular case, as the weld metal has cooled rapidly, sufficient time was not available for the formation of a thick-continuous grain boundary austenite and the Widmanstatten austenite, and therefore the weld metal has retained a good amount of metastable ferrite.

The above discussion brings out the fact that the rapid cooling of SDSS without change in chemical composition shall always result in higher ferrite content than the equilibrium level. This is substantiated by the heat affected zone (HAZ) microstructures depicted in Figs. 4 and 5, revealing the presence of a predominantly ferritic structure with very small amounts of austenite. Coarsening of the grains in the HAZ is due to the heating of these regions well above the solvus temperature.

Fig. 6 shows the microstructure of the weld metal obtained by GTA welding process with helium as the shielding gas. The use of helium as shielding gas has resulted in higher heat input (1.70 $kJ.mm^{-1}$) when compared to that of GTAW with argon (1.13 $kJ.mm^{-1}$). This enabled the formation of relatively higher amounts of austenite in the weld metal.

Weld metals produced with (argon + carbon dioxide + oxygen) shielding gas mixture have distinctly different microstructural features. The microstructure of this weld metal has a characterisitic cellular structure as shown in Fig. 7. As is evident from that figure, the entire austenite in the weld metal seems to have been confined to the grain boundary region, which is supplemented by the higher magnification photomicrograph given in Fig. 8. During solidification the formation cellular structure is favoured with high ratio of solidification rate to growth rate. In this case, it is possible that the presence of oxygen might have offered larger number of nucleation sites by forming fine oxides. This could not be ascertained in the current study as neither the characterization with electron microscope nor the impact toughness studies have been carried out.

The hardness of the weld metals produced by GTA welding process with different shielding gas mixtures and SMA welding process are listed in Table 3. As could be noticed from that there is literally not much of a variation in the weld zone hardness values despite the fact that there exists a different morphological-microstructural feature and variation in ferrite/austenite ratio. Further, hardness measurements taken on individual phases viz., ferrite and austenite, do not show large differences.

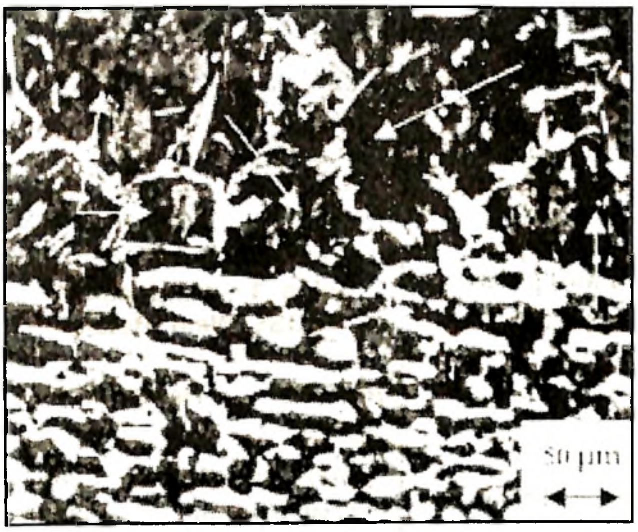

Fig. 5 : Microstructure of GTA weld HAZ (arrows show coarse ferrite grains)

Fig. 6 : Microstructure of helium gas shielded GTA weld metal (note higher amounts of austenite)

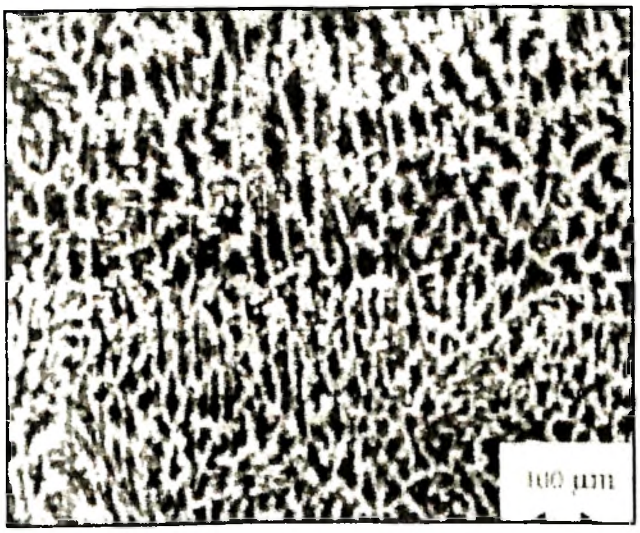

Fig. 7 : Microstructure of Ar+Co_2+O_2 shielded GTA weld metal

Fig. 8 : Microstructure of Ar+CO2+O2 shielded GTA weld metal (note cellular structure)

Table 2 : Welding Parameters

Process	Voltage V	Current A	Speed $mm.min^{-1}$	Heat input $Kj.mm^{-1}$	Electrode Covering Shielding gas / gas mixture	Gas flow rate $L.min^{-1}$
SMAW	23	140	100	1.90	Rutile type	—
GTAW	12	110	70	1.13	Argon type	8
GTAW	18	110	70	1.70	Helium	10
GTAW	15	120	85	1.27	Ar(74%)+CO2(25%)+O2(1%)	8

On transformation from ferrite to austenite, it is expected austenite stabilizers such as nickel and nitrogen partition to the austenite phase, while the ferrite region in the welds is enriched with ferrite stabilizers viz.. chromium and molybdenum. Even though only a small amount of nitrogen, whose interstitial hardening abilities are well known, is present in the weld metal, all of them get partitioned to austenite and thus compensate for the solid solution hardening of ferrite. Therefore, the hardness values of the different weld metals do not vary much.

CONCLUSIONS

The morphological features of austenite in the weld metal are controlled by the composition and the heat input.

SMA welding with nickel fortified filler helps in achieving a near-equal balance of ferrite-austenite ratio in the weld metal

The shielding gas/gas mixture has got a decisive influence on the ferrite-austenite ratio and the morphological features of the same

Hardness of the SDSS weld metal is not influenced by the welding processes and microstructure

Table 3 : Hardness of SDSS Weld Metals

Process	Hardness HV1
SMAW	271
GTAW (Argon)	268
GTAW (Helium)	258
GTAW (Ar+CQ+OZ)	262

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