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Effects of Nitrogen added Argon Gas flow rate on the Mechanical and Corrosion properties of Duplex Stainless Steel Gas Tungsten Arc welds.

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Abstract

This study investigates the effect of adding nitrogen to the weld metal on the mechanical and corrosion properties of 2205 Duplex Stainless Steel gas tungsten arc welds. Shielding gas mixture of Argon + 2% Nitrogen was used with gas flow rate varied between 10-20 Liters per minute, to join 6 mm thick plates using 2209 filler. As a result of varying gas flow rate nitrogen content in the weld metals varied from 0.1 % - 0.25 %, resulting in changes in weld metal microstructures, corrosion and mechanical properties. Tensile testing of welds showed that joints made using pure argon failed in the weld metal while those with nitrogen additions failed outside the weld metal and exhibited better Tensile strength. Weld Metals containing nitrogen were found to exhibit better pitting corrosion resistance and higher the nitrogen content in the weld metal, better the pitting potential. It has been concluded that increase in the gas flow rate while using Argon + 2% Nitrogen mixture as shielding gas increases the weld metal nitrogen content, resulting in decreased ferrite content in the weld metal and stronger weld joints, while improving the pitting corrosion resistance.

Keywords: Duplex stainless steel, Gas Tungsten Arc Welding, Liters per minute, Nitrogen, Pitting corrosion

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Introduction

One of the important processes for welding stainless steels with good quality and surface finish is Gas Tungsten arc welding(GTAW)[1]. Duplex stainless steel (DSS) contains approximately equal proportions of body-centered cubic ferrite (α) and face-centered cubic austenite (γ). Austenite stabilizers, such as nickel and nitrogen, promote the formation of austenite (γ phase), while ferrite stabilizers, such as chromium and molybdenum, promote formation of ferrite (α phase) respectively[2-4]. Although the content of α to γ phase in duplex stainless steel is usually about 50% each, it can vary between 30% and 70 % and most commonly between 40% and 60% [5-6]. Duplex stainless steels offer superior mechanical properties and better corrosion resistance to chloride-induced stress corrosion cracking than most types of other stainless steels [7–9].

The higher mechanical strength combined with better corrosion resistance has made Duplex stainless steel find more applications in industries such as Nuclear, Gas and oil refineries, offshore structures, paper, chemical and wastewater. Normally Argon is used as shielding gas to provide clean welds with a relatively low spatter and a constant arc in Tungsten inert gas (TIG) welding. It is recommended to use a filler having higher nickel content such as 2209 with about 9% nickel as against the 5% nickel in the base material 2205.This is done to maintain the austenite to ferrite ratio in the weld metal. As a strong austenite stabilizer nitrogen can lead to solid solution strengthening and raise the Ferrite/Austenite transformation temperature and assisting the formation of more Austenite in the weld metal[10-12]. Presence of Nitrogen has a significant effect on pitting corrosion resistance, equivalent to 16 times that of Chromium, and an austenite-stabilizing effect equivalent to 30 times that of Ni and therefore can replace expensive Ni as an alloying element. Nitrogen added to Argon shielding gas increases the pitting corrosion resistance by dissolution of Cr_2N in α-phase, Nitrogen also improves mechanical properties even when present in small amounts such as 0.1 – 0.3 wt.%[13,14]. Therefore nitrogen addition is important and decreases the corrosion and ferrite phase , which is susceptible to hydrogen embrittlement [15]. In the current work Gas flow rate has been varied while using Ar + 2% N_2 shielding gas. The paper describes the effect of Nitrogen and flow rate on the microstructure, Mechanical properties and pitting corrosion of the weld fusion zone.

Experimental Procedure

The Material selected for studies were Duplex Stainless steel plates (UNS32205) of thickness 6mm plates were cut into 100 x 200 mm size, roughly polished with silicon carbide paper and cleaned with acetone. Welds were made using Manual GTAW by using shielding gas mixture of Argon +2% Nitrogen with different gas flow rates, as mentioned in Table 2. The filler metal used is 2209 wire, whose chemical composition is given in Table-1 along with base metal composition.

Weld metal Ferrite content was estimated using Fisher Ferritoscope. The average value of 10 measurements taken from different locations on the polished samples of weld metal are presented Table 3. Nitrogen content in the weld metals were determined using LECO TC500(inert fusion method). Drilled pieces from weld metal were used to find the % nitrogen. Tests were conducted according to ASTM E1019 standards. Metallographical examinations were performed to reveal microstructure in base and weld metals of DSS. The welds were ground to 1200 grit using SiC abrasive papers, polished with diamond paste and etched using Murukami reagent (10 grams of potassium ferro cyanide + 10 grams of Potassium hydroxide and 100ml of water).

To analyse the effects of nitrogen in the shielding gas on the pitting corrosion resistance of 2205 DSS plates, potentiodynamic polarization tests were conducted using a Software based PAR Basic electrochemical system. Saturated calomel electrode (SCE) and carbon electrode were used as reference and auxiliary electrodes respectively .All the experiments were conducted in 0.5 Mole H_2SO_4(49ml in one litre) + 0.5 Mole NaCl (17gm in one litre)solutions with pH

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adjusted to 4. The potential scan was carried out at 0.166 mV/sec with initial potential of –0.25V (OC) SCE to final potential of pitting. The exposure area for these experiments was 1 cm^2. The potential at which current increases drastically was considered as critical pitting potential (E_{pit}). Specimens exhibiting relatively more positive potential, (or less negative potentials) were considered as those with better pitting corrosion resistance.

Transverse tensile tests were conducted to determine the tensile properties of different welded joints. Tensile test were carried out on three specimens from each welding procedure to find the tensile strength and elongation of the weldment. The design and dimensions of the tensile specimens were in accordance with ASTM E8 standard.

Results and Discussion

The DSS base material microstructure is shown in Fig. 1, which has dual Ferrite-Austenite phase banded structure. During welding the weld metal solidifies as ferrite, which on further cooling partially transforms to austenite. The amounts of Ferrite & Austenite depend on material composition and cooling rate. Faster cooling rates experienced by weld metals result in higher ferrite and lower austenite compared to base material. To undo this effect and to maintain austenite to ferrite ratio high Nickel fillers such as 2209 are used.

Nitrogen in Weld metal

The nitrogen content in the weld metal obtained by adding 2% nitrogen gas along with Argon in the shielding gas with different gas flow rate is shown in Table 3. According to Speidel[16] distinctive challenges were faced in Nitrogen alloying since the solubility of nitrogen in Fe-based alloys and liquid-Fe is restricted at atmospheric pressure. However, the nitrogen solubility can be improved by increasing the nitrogen gas pressure above the melt and through alloying additions. Nitrogen in the gas will cause a nitrogen pick-up in the weld deposit. This will give a higher portion of austenite in the weld and much lower risk of nitride precipitates in ferrite grains close to the surface of the weld. The results clearly shows as the gas flow rate is proportional to nitrogen content in the weldmetal.

The ferrite contents of the different weld metals, measured magnetically are given in Table 3. As can be observed from the table GTA weld metals contain lesser amount of ferrite as the nitrogen levels in weld metals keep increasing. This suggest that inclusion of nitrogen in the shielding gas and the flow rate play an important role in controlling the phase balance. The important reason is that of-course the addition of nitrogen through shielding gas not only shifts the thermodynamic equilibrium towards a higher austenite fraction but also increases the (α + γ)/α solvus, so that the $\alpha \rightarrow \gamma$ transformation takes place at higher temperature. The base metal in the as received condition contains 0.14% N and 54% ferrite. When this is GTA welded using pure argon as shielding gas and 2209 filler the phase balance sifts to 45% ferrite and 55% austenite with a lowering of nitrogen content in the weld metal to 0.11%. In the remaining welds where Ar + 2% N_2 is used as shielding gas with varying flow rates, Nitrogen content in the weld metal increases with increase in flow rate resulting in higher austenite content in weld metals. This shows the significant role played by gas flow rate in changing the phase balance in the weld metal.

Microstructures

A high nitrogen content can produce nitrogen gas porosities[17], the gas pores were formed during solidification due to separation of nitrogen in liquid and low nitrogen solubility in ferrite. In common, austenite in DSS weld metal is produced from ferrite in three modes, viz , (i) at prior-ferrite grain boundaries as allotriomorphs (ii) widmanstätten side-plates growing into the grain (iii) as intergranular precipitate. However, austenite present within the grain(Fig. 2a-d) has widmanstätten austenite intercepted transverse long axis. The microstructure of the weld metal welded with nickel- enriched filler metal is qualitatively(Fig. 2a) shows the proportionate of austenite greater than base metal Due to increase in shielding gas flow rate nitrogen increases from 0.11 to 0.25 wt.% in different welds as shown in Table 3. The ferrite content decreases from 54% in the base metal to 32% in the weld with highest Nitrogen content. Careful microstructural studies revealed no porosity. The optical microscopy of the DSS weld with 0.1176 % wt. (Argon weld) shows the microstructure fully ferritic solidification followed by widmanstätten austenite transformation.(Fig. 2a-d). The DSS with 0.11 to 0.25 wt.% N (Fig. 2a-d) shows coarse austenite phase along ferrite grain boundary.

Hardness

Vickers hardness measurements(5 kg load)on different weldments were conducted and the results are shown in Fig. 4. In general MicroHardness increased with increase in nitrogen content across the weld. Interstitial solute like nitrogen and carbon wield much greater strengthening effect than substitutional atoms like Cr, Mn, Mo, etc [18]. It has been found that the ferrite and austenite phase do not change much in composition because substitutional elements do not have time to partition significantly during DSS welding .Microhardness measurements of ferrite/austenite graind in the GTA welds exhibit that austenite were marginally harder than ferrite. Nitrogen is a strong austenite stabilizer , Interstitial solid strengthening by nitrogen is much well-defined in Austenite phase than in ferrite phase. This results in increased hardness of ArN3, ArN2, & ArN1 weld metals as shown in Fig. 5.

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Tensile strength

The DSS with various gas flow rates and addition of nitrogen result in retaining the strength and ductility in the weldments. The nitrogen % varies between o.1176 – 0.2564 with increasing in tensile strength and fracture occurs in base metal. According to Rawers et al. [13]the two possible strengthening method have been proposed: (i) matrix strengthening mechanism due to the interaction between the interstitial nitrogen and dislocations in matrix, which is proportional to $[N]^{1/2}$; (ii)Dislocation-nitrogen drag interaction mechanism resulting from the nitrogen being carried along with the dislocation as its moves through the lattice, which is proportional to [N**]. **According to Pickering[19], the staking fault energy (SFE) of a stainless steel decreases with increase in nitrogen content. As a consequence, the separation between two partial dislocations will be broad, which causes the dislocations to be confined to their slip plane and to form pile-ups. This in turn, give rise to higher work hardening rate, tensile strength and uniform elongation as shown in Table 4.

Tensile test of the argon weldment failed on the weldmetal(Fig. 3a), while ARN1, ArN2 & ArN3 weldments(Fig. 3b-d) failed outside the weldmetal. Normally engineering materials have either ductile or brittle mode failure. Fig. 4(a,b) shows the SEM image of the Argon and Argon + Nitrogen tensile fracture surface. The microstructures exhibited from tensile fracture surface reveals the ductile fractures in the form of microvoids.

Pitting Corrosion

Potentiodynamic polarization curves were obtained in sodium chloride solution for all the weldments. some authors have tried to correlate pitting corrosion resistance with chemical composition and found that Cr, Mo and N elements will have impact on pitting corrosion resistance. Pitting corrosion resistance of weld metal increased with increase in the nitrogen content.

Weld metal without addition of nitrogen exhibits pitting potential(E_{pit}) similar to that of the base metal. But in case of welds where nitrogen has been added significant improvement in E_{pit} values(Table 4). Dynamic polarization curves presented in Fig. 6 show that ArN3 exhibited better pitting corrosion resistance. The pitting potential values indicate the potential at which the onset of pitting takes place, and the higher values indicate better pitting corrosion resistance.

Conclusion

1. Increased gas flow rate while using Ar+2%N shielding gas increases the weld metal nitrogen content significantly.
2. Addition of Nitrogen to the shielding gases increase the Tensile strength and hardness. Use of Ar + 2%N results in better mechanical properties of the welded joints compared to those made using pure Argon as shielding gas.
3. Increasing the gas flow rate of Ar+2%N subsequently increase the pitting corrosion resistance, due to the higher amount of nitrogen and austenite in the weld metal.

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Table 1 Chemical Compositions of base and filler materials, wt.%

	C	Si	Mn	S	P	Cr	Ni	Mo	N
Base Metal 2205	0.02	0.33	1.7	0.002	0.02	22.71	5.40	3.02	0.14
DSS Filler 2209	0.013	0.51	1.51	0.001	0.001	22.92	8.67	3.14	0.15

Table 2 Welding Parameters

Shielding Gas	Gas flowing rate (LPM)	Voltage (V)	Welding current (A)	Electrode	Welding speed (Approx)	No of Passes
Argon, Argon + 2% Nitrogen	10, 15, 20	10-12	60 – 80	ER2209, Dia 1.6 mm	120 mm/min	6

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Table 3 **Weld specimen Designations, Gas Flow rate, Nitrogen percentage & % Ferrite of DSS welds**

S.No	Weld	Specimen Designation	LPM (Gas Flow Rate)	% Nitrogen	% Ferrite
1	BaseMetal	BM	-	0.14	54
2	GTA Weld - pure Argon	Ar	15	0.11	45
3	GTA Weld - Argon +2% Nitrogen	ArN1	10	0.18	38
4	GTA Weld - Argon +2% Nitrogen	ArN2	15	0.19	36
5	GTA Weld - Argon +2% Nitrogen	ArN3	20	0.25	32

Table 4 **Tensile & Pitting Corrosion properties of DSS welds.**

Specimen Designation	UTS (MPa)	Elongation	Pitting Potential E(pitt) mV
BM	754	35	900
Ar	690	26	910
ArN1	710	29	925
ArN2	725	28	940
ArN3	735	31	950

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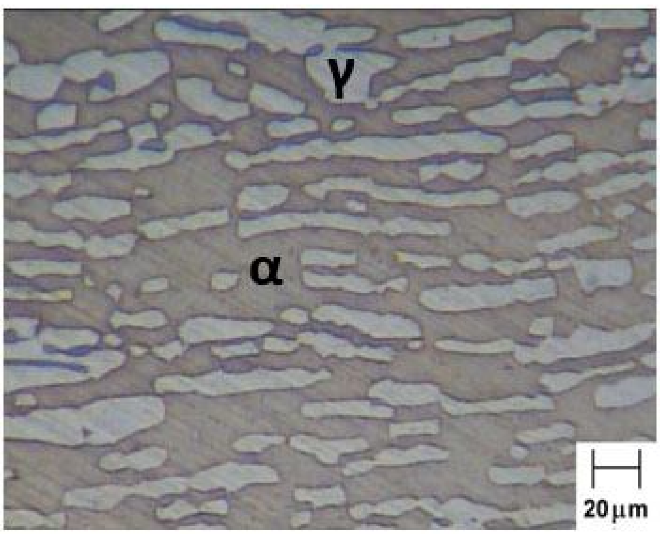

Figure 1

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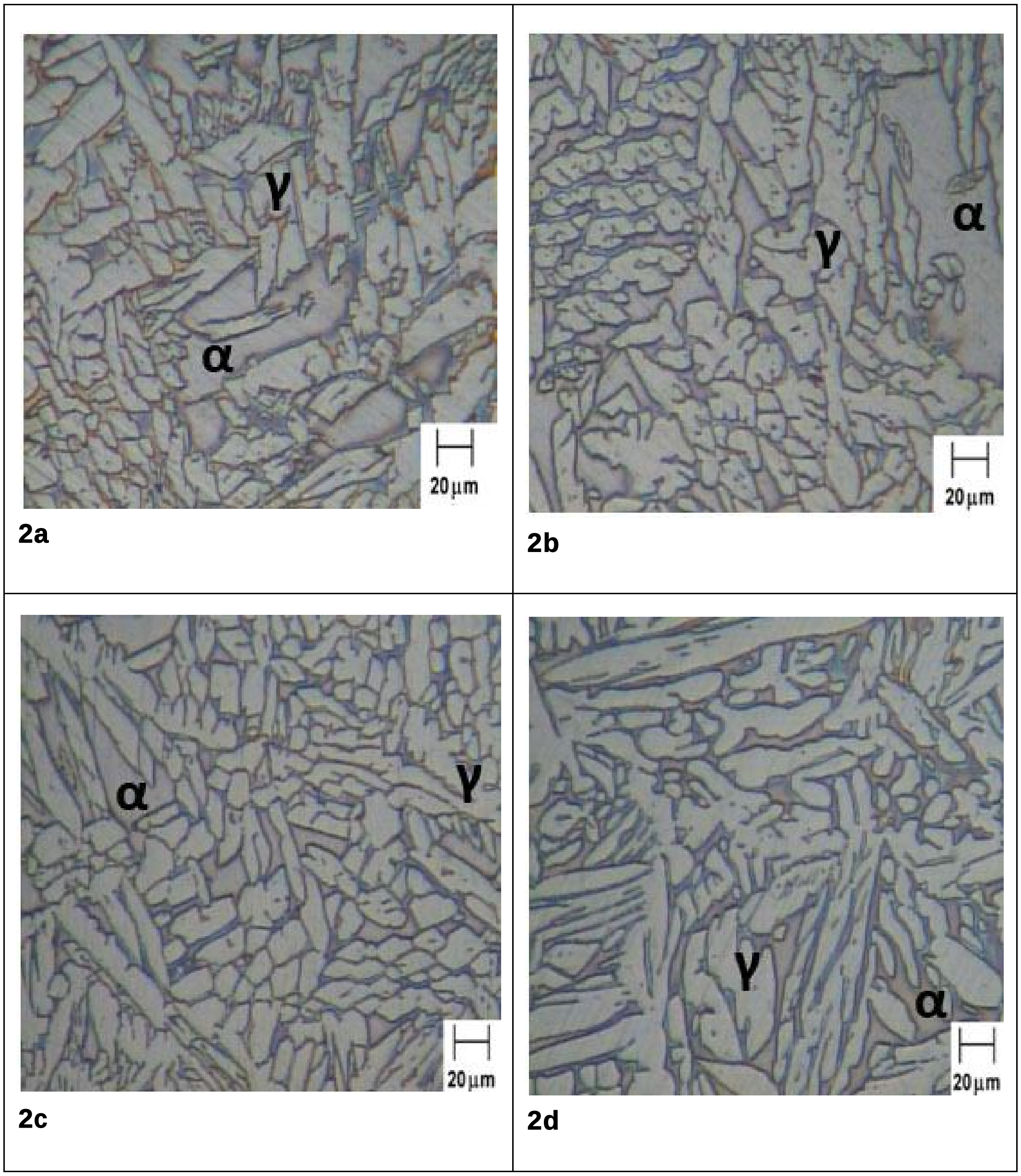

Figure 2

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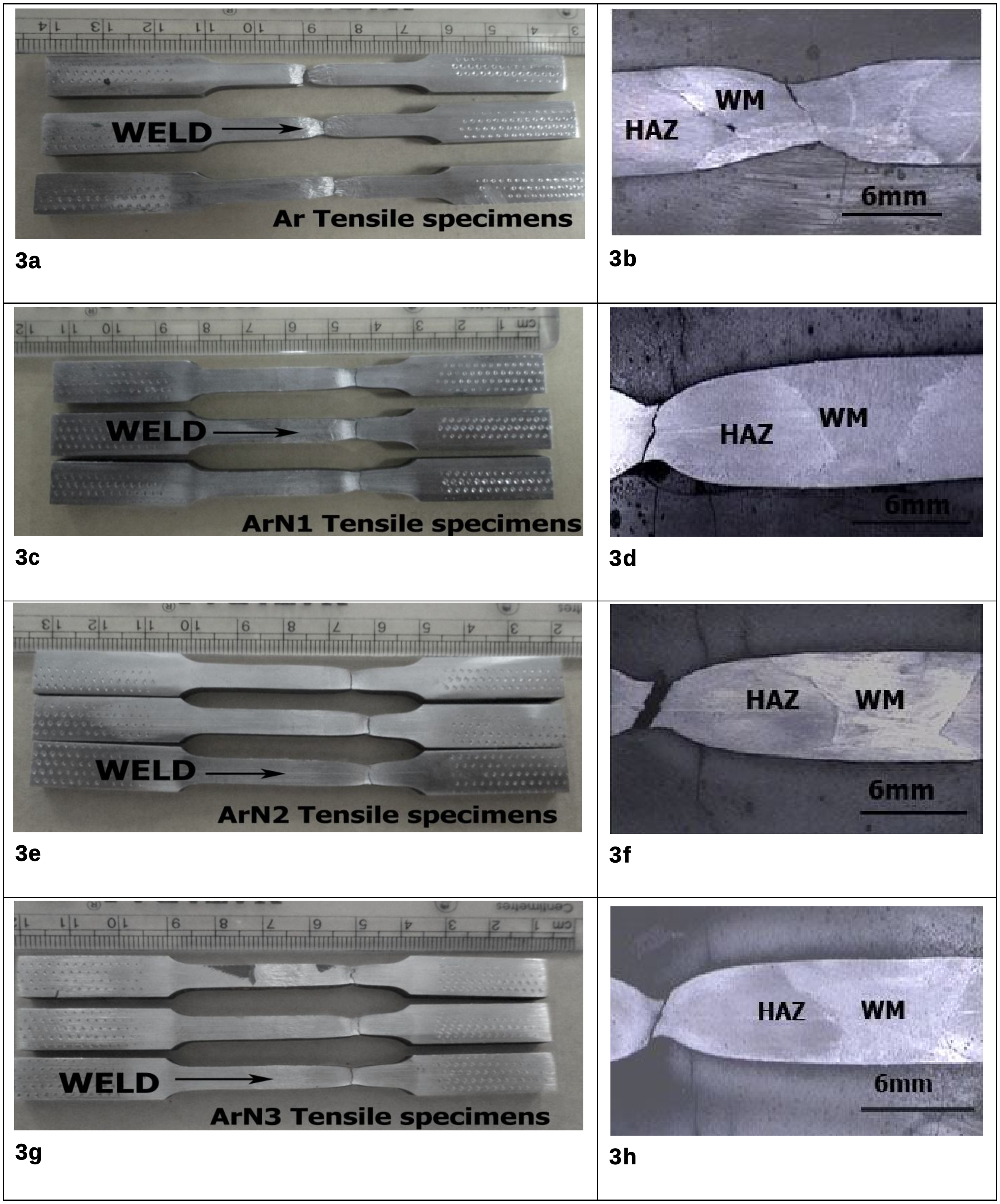

Figure 3

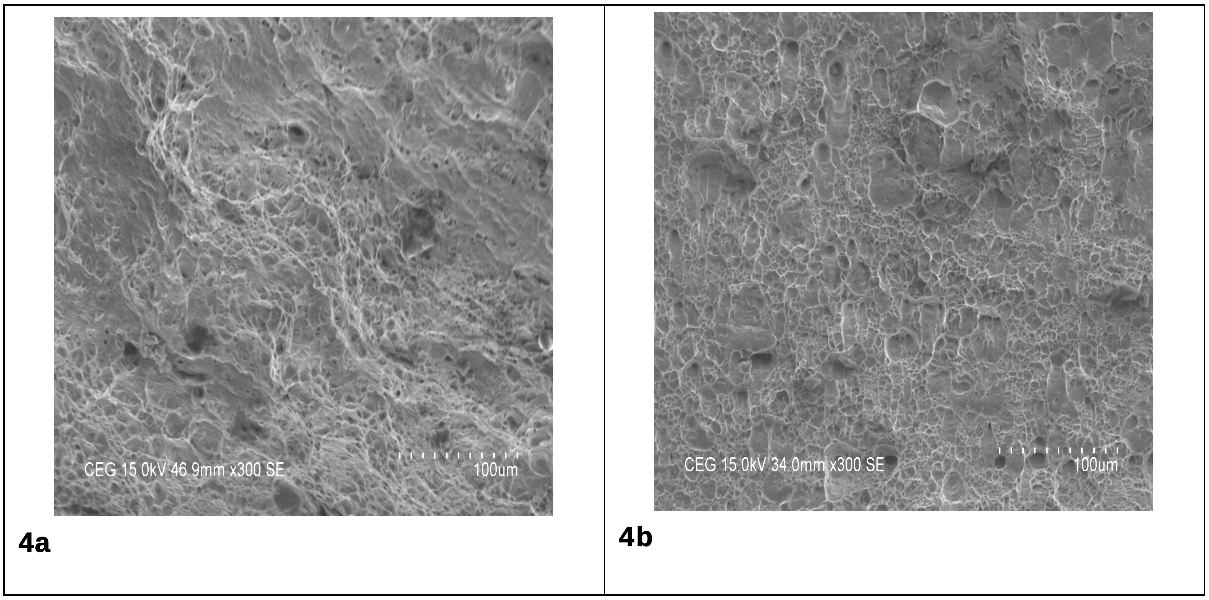

Figure 4

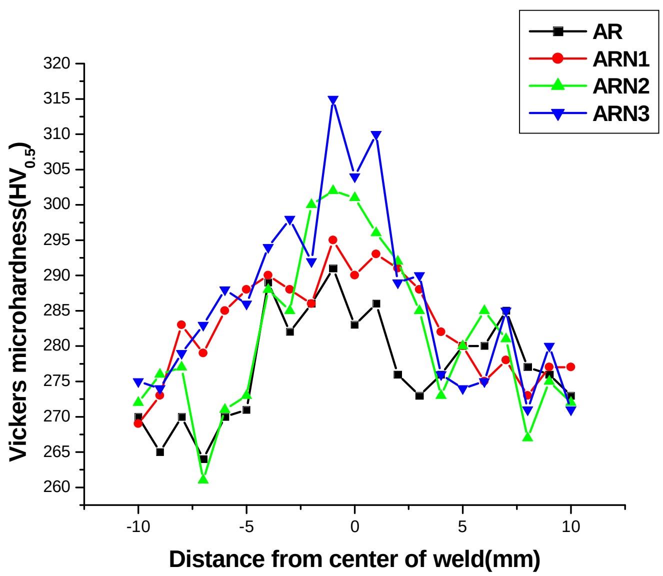

Figure 5

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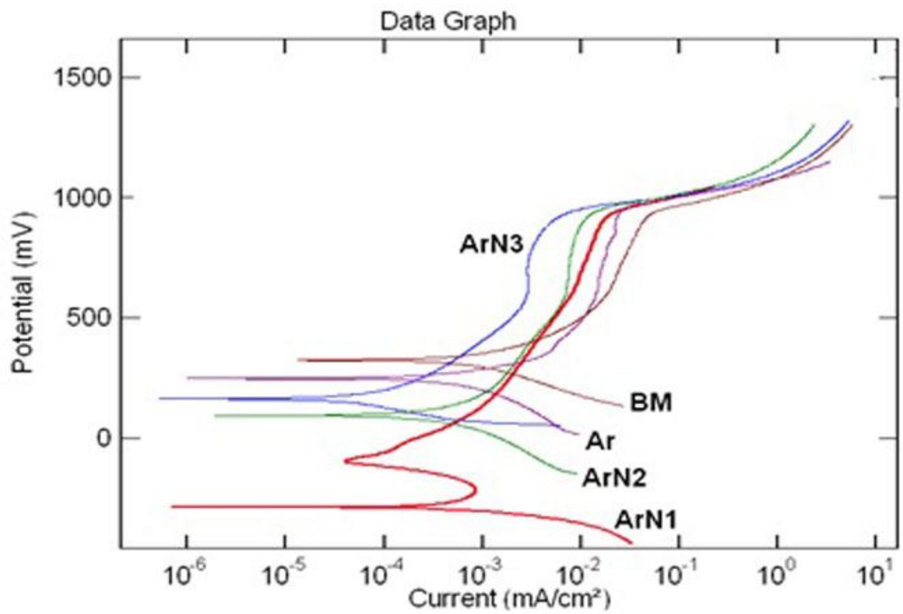

Figure 6