



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

**Volume 9, Issue 9, September 2020**

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 7.512**

9940 572 462

6381 907 438

[ijirset@gmail.com](mailto:ijirset@gmail.com)

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# Study on the Effect of Nitrogen as a Shielding Gas on Tungsten Inert Gas Welding of Duplex Stainless Steel

Umapathi K <sup>1</sup>, Ravibharath R <sup>2</sup>, Dr. Anandavel B <sup>3</sup>, Noorullah D <sup>4</sup>

P.G. Student, Department of Metallurgical Engineering, Government College of Engineering, Salem,  
Tamil Nadu, India<sup>1</sup>

Manager, Welding Research Institute, BHEL, Trichy, Tamil Nadu, India<sup>2</sup>

Assistant Professor, Department of Metallurgical Engineering, Government College of Engineering, Salem,  
Tamil Nadu, India<sup>3</sup>

Head of the Department, Department of Metallurgical Engineering, Government College of Engineering, Salem,  
Tamil Nadu, India<sup>4</sup>

**ABSTRACT:** Gas tungsten arc welding process is mostly applied for fabricating duplex stainless steel components. The phase balance (ferrite and austenite) cannot be maintained by the welding process alone, so by using different proportion of nitrogen as a shielding gas in argon gas mixture and by using ER2594 and ER2209 filler metals the phase ratio was balanced. In this present study work describes the influence of nitrogen and filler metals on the phase balance of duplex stainless steel welds. The ferrite number measurements, macrostructure microstructure and hardness will provide the information regarding the influence of nitrogen as a shielding gas and filler metals to obtain approximately 50:50 phase balance after the welding. The objective of this paper was to evaluate how nitrogen content in the shielding gas will show the effects on the microstructures and to investigate the changes in ferrite content of the DSS welds.

**KEYWORDS:** GTAW, Duplex stainless steel, ER2594, ER2209, shielding gas nitrogen content, Ferrite number, etc.

## I. INTRODUCTION

Duplex stainless steels (DSS) are two phase materials consisting of  $\gamma$ - austenite (face centered cubic (FCC)) and  $\alpha$ -ferrite (body centered cubic (BCC)). They are characterized by a combination of excellent mechanical properties and corrosion resistance. In the last decade, interest has increased in various industries, such as oil and gas, paper and chemical industry [6]. DSS combines the attractive properties of austenitic and ferritic stainless steels: high tensile strength and fatigue strength, good toughness even at low temperatures, adequate formability and weldability, and excellent resistance to stress corrosion cracking, pitting, and general corrosion [1]. Among the growing application of high strength steels, duplex stainless steels (DSSs) are gaining increasing attention from the chemical, petrol, and transportation industries, thanks to their mechanical properties and corrosion resistance [10]. They find increasing use as an alternative to austenitic stainless steels, particularly where aggressive anions such as chloride or bromide in high concentrations are present. The advantage of the duplex alloys in media that contain halide, such as chloride or bromide, resides in the content of the delta ferrite, which promotes combined effects due to electrochemical and mechanical factors. Owing to the two different elastic limits, lower in austenite than in ferrite, plastic deformation under external load concentrates on the austenite, while ferrite acts as an anode protecting the austenite, which acts as the cathode [1]. The introduction of modern grades with better properties and a competitive price have increased their use, for example, in offshore industries, petrochemical plants, and naval constructions. In the fabrication of equipment made from stainless steels such as pipe, automotive, exhaust gas systems, chemical industrial equipment, etc., arc welding using shielding gas is often used [1].

Even though the weldability of such steels has been reported to be good, there remain problems in welding of these materials. One such problem is the formation of secondary austenite, especially in multiple pass welding. The secondary austenite seems to have a significant adverse role with regard to corrosion properties, in particular in weldments exposed to aggressive environments. The presence of secondary austenite in the weld metal has been reported to be detrimental in such environments [2].

Tungsten inert gas (TIG) welding is one of the commonly used welding methods. So, TIG welding, which uses a non-consumable tungsten electrode and an inert gas for arc shielding, is an extremely important arc welding process. In this process, an electric arc is formed between a tungsten electrode and the base metal. The arc region is protected by an inert gas or a mixture of gases. In TIG welding, the shielding gas plays an important role. The composition of a shielding mixture in arc welding depends mostly on the kind of material to be welded. Specifically, nitrogen is added to the argon shielding gas to control the delta-ferrite content in the weld metal, which can indirectly affect the weld pool shape [1]. Nitrogen addition to the shielding gas increases the arc voltage and consequently the heat input, which increases the peak temperature of the weld metal and reduces the cooling rate. It also causes a rise in the amount of nitrogen in the weld. Increase in nitrogen addition to the argon shielding gas increases the magnitude of the heat input [7]. Nitrogen is one of the most important elements in improving the corrosion resistance and mechanical properties of HAZ and welds. It can retard the precipitation of the intermetallic compound by raising the delta ferrite to the austenite transformation temperature and assisting the reformation of the austenite phase in HAZ. Meanwhile, nitrogen has a stronger solid solution strengthening capability and lowers the stacking fault energy, which consequently increases the strength of DSS. It can also improve the passivation behavior, facilitate the re-passivation process of the base metal within the pit, increase the pitting potential, and promote the surface adsorption of the  $\text{NH}_4^+$ . Therefore, the addition of nitrogen has become popular because of these multiple beneficial effects [1]. It is important to study the role of nitrogen introduced through the shielding gas on solidified structures, because nitrogen introduced during welding has two roles to play [1],

—It crucially influences the solidification mode and, hence, the room temperature microstructure of the weldment.

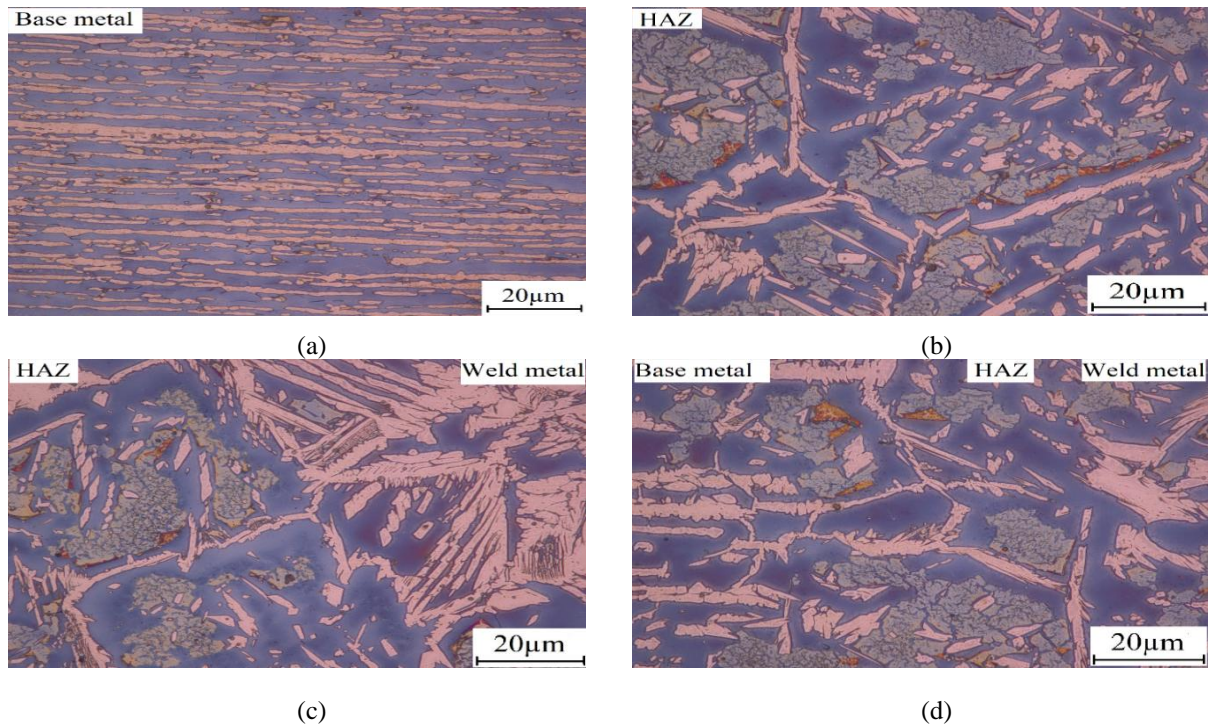
—As in the case of nitrogen-containing wrought alloys, it improves the localized corrosion resistance.

Nitrogen increases the corrosion resistance, especially of the austenite phase. Nitrogen is a strong austenite stabilizer which increases the temperature of the transformation to the austenite phase.

A part of the nitrogen which exists in the metal may be lost during welding and it has been observed that weldments of nitrogen containing duplex stainless steels suffer from pitting attack due to this nitrogen loss. The loss of nitrogen from the weld pool appears to result from the difference in partial pressure between the nitrogen dissolved in the weld pool and the gas directly above the weld pool. The loss of nitrogen from the weld pool can be modified by using a shielding gas containing a proportion of nitrogen [7].

The use of pure argon or helium as the shielding gas generally results in nitrogen loss. The higher amount of ferrite is produced with argon shielded than with helium-shielded weld metal. Since helium yields a hotter arc, it provides a suitable cooling rate for transfer from the  $\alpha$  to  $\gamma$  phase, which improves the impact toughness of the weldment. Ferrite-rich weld metal in an argon-shielded weld has poorer corrosion properties and lower hardness than helium-shielded weld metal.

The addition of nitrogen into the shielding gas accelerates the partial transformation from ferrite to austenite during cooling after welding. Increased austenite improves the weld pitting corrosion resistance and it has been observed that intergranular austenite impedes pit propagation within ferrite weldments. Nitrogen can also help homogenization of chromium distribution in the two ferrite and austenite phases [7]. Recent work [5] has indicated that the level of nitrogen in the shielding gas should match the nitrogen level in the parent metal; for instance, for a duplex stainless steel with a typical nitrogen content of 0.16 %, the shielding gas should contain 1.0–1.2 % nitrogen, and for a super duplex stainless steel with a typical nitrogen content of 0.25 %, the shielding gas should contain 2.0–2.5 % nitrogen, to obtain a weldment nitrogen content similar to the parent metal. If the nitrogen content of the liquid weld pool exceeds the solubility limit, it may cause porosity in the weld since the excess nitrogen escapes from the pool during solidification. Out-gassing may also produce spitting or sparking [5]. Welding of duplex stainless steel is rather challenging since it is necessary to ensure that the phase balance in both the weld deposit and the heat-affected zone is maintained; otherwise, an optimum combination of mechanical properties and corrosion resistance may not be achieved. An important improvement occurs with the introduction of nitrogen as one of the main alloying elements [7].



**Fig 1.** Typical microstructure of a 2205 DSS weld, (a) Base metal, (b) HAZ, (c) Region between HAZ And Weld metal interface, (d) Region between Basemetal, HAZ And Weld metal interface.

However, after welding the phase balance can be easily shifted to a mostly austenitic or mostly ferritic microstructures, depending on the welding process and heat input. In order to determine the phase ratio, several methods are available to use, such as Feritscope measurements, ASTM E562 manual point count method (on metallographic images) or quantitative image analysis. The heat affected zone (HAZ) of DSS welds are usually more ferritic, contrary to the weld metal (WM), which can be more austenitic in case of nitrogen-containing shielding gases, nickel over-alloyed filler metal and multi-pass welds. The unbalanced microstructure (more ferritic or more austenitic) after welding of a DSS can result in the loss of mechanical properties and corrosion resistance. This is the reason why measurement of the phase balance is mandatory after DSS welding.

Under industrial conditions, magnetic induction based Feritscopes are mainly used for phase ratio quantification. These instruments calculate the ferromagnetic phase ratio (ferrite in DSS) in a given volume. This measured volume is dependent on the penetration depth of the eddy-current used for excitation. The phase measurement with a Feritscope is limited; only the WM and base metal (BM) phase ratio can be measured accurately. The HAZ is usually very narrow (100–200µm) due to the maximum recommended heat input for DSS welding is 2.0 kJ.mm<sup>-1</sup>. This narrow region causes uncertainty at the positioning of the probe, and the excited volume is usually greater since the Feritscope is also measuring either WM or BM as a part of the HAZ results.

The main studies of DSS welds are focused on metallurgical and mechanical aspects rather than on electrochemical corrosion behavior. The objective of this paper was to evaluate how nitrogen content in the shielding gas will show the effects on the microstructures and to investigate the changes in ferrite number of the DSS welds.

## II. MATERIALS AND METHODS

### A. DUPLEX STAINLESS STEEL BASE MATERIAL

The chemical composition of the used base material (UNS S32205, in this paper it is designated by abbreviation “2205 DSS”) grade along with filler metals ER2594, ER2209 can be seen in Table 1. The chemical composition was measured by a PMI Master Sort optical emission spectroscopy.

Bead on tube welding experiments were carried out on the duplex stainless steel 2025 DSS base metal using ER2594 and ER2209 filler metal.

The dimensions of the tube measured was, Length- 146 mm, Thickness -3 mm, Outer diameter -115 mm, internal diameter-109 mm. The process parameters used for GTAW are given in table 2.

The shielding gas used was 99.99% pure argon having a flow rate of Ar- 10 L/min, N<sub>2</sub>-10 L/min, Purging Ar- 5 L/min. The polarity used in the welding was direct current straight polarity (DCEN).

The magnetic induction based Feritscopes are mainly used for phase ratio quantification. The used instrument was a Fischer FMP 30 Feritscope. The Feritscope measurements were done in 10 points on the face side along with equal distances. This instruments calculate the ferromagnetic phase ratio (ferrite in DSS) in a given volume. This measured volume is dependent on the penetration depth of the eddy-current used for excitation. Then the welding was done circumferentially around the tube, four different level of nitrogen gases were used as shielding medium; pure argon, Ar-2% N<sub>2</sub>, Ar-5% N<sub>2</sub>, Ar-10% N<sub>2</sub> and while welding the use of filler metal is used in the given order; without filler, with ER2594 filler and with ER2209 filler metal. By using different combinations of shielding gas and filler metals, 12 different weld bead were obtained. The resultant weld metal designation are given in table 3. After welding, using Fischer – Feritscope, again the ferrite number were measured at the same exact points measured before welding. This gives details regarding the amount of ferrite number changing before and after welding.

**Table 1:** The nominal Chemical Composition of Base Material Duplex Stainless Steel (2205 DSS), and the Filler Metals- ER2594, ER2209

ELEMENTS	Cr	Ni	Mn	Mo	P	S	C	N	Fe
2205 DSS	21.98	5.40	1.46	3.35	0.03	0.02	0.019	0.15	Balance
ER2594	25	9	2.5	3.25	0.03	0.03	0.03	0.16	Balance
ER2209	23.5	9.3	1.2	3.45	0.03	0.03	0.03	0.18	Balance

After the ferrite number measurements are taken, the distance between ripples in weld bead on tube were measured to relate the solidification rate with the use of different combinations of shielding gas and filler metals. Measurement Principle and Method in this work, the formation and the characteristics of ripples were seriously considered. For ripples, apart from the appearance observation, other criterion, which is the distance of ripples, can be used to quantitatively describe the characteristic. Hence, this work also employed the distance of ripples as the evaluation criterion for the ripples in each experiment. In general, the distance of ripples referred to the length of the weld bead between the tops of two adjacent ripples, as shown in Figure 3 and 4 [8].

The first method is shown in Figure 3. Ten ripples were selected in the middle of the weld bead, then the total length can be measured, which was marked as L. Hence, the average distance of ripples can be obtained as follows:

$$W_{av1} = L/10 \quad (1)$$

The second measurement is shown in Figure 4. In this method, 10 single ripples were selected and then the distance of each ripple was obtained; then the average distance of the ripples was obtained as follows:

$$W_{av2} = (W_1 + W_2 + \dots + W_9 + W_{10})/10 \quad (2)$$

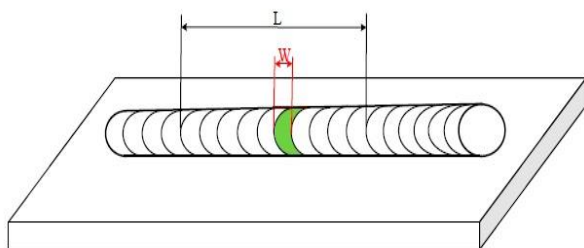
The accuracy of the measurement of the distance of the ripples was very important.

Hence, above two measurements were combined. During the data processing, two stages, who were marked as A and B, respectively used the first and second methods to obtain corresponding results.

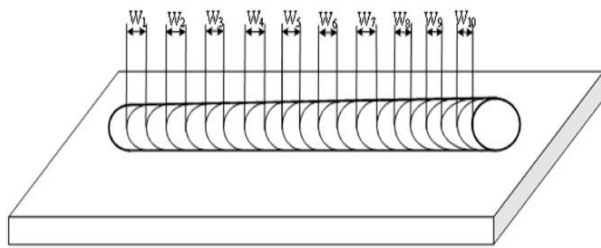
Four measurement results were obtained for each weld bead. Then the final distance was the average value of the four results. The calculation can be shown as follows:

$$W_{av} = (W_{av1A} + W_{av1B} + W_{av2A} + W_{av2B})/4 \quad (3)$$

It can be noticed that combining two measurement methods and using the average value as the final distance can decrease the systematic error and human measurement error, and measuring several times can decrease the random error [8].



**Fig 2.** The schematic representation of the distance of ripples and the first measurement method.



**Fig 3.** The schematic representation of the second measurement method of the distance of the ripples.



**Table 2:** Welding Process parameters

Welding process	GTAW
Filler metal	ER2594, ER2209
Shielding gas	Ar // Ar-2% N <sub>2</sub> // Ar-5%N <sub>2</sub> // Ar-10% N <sub>2</sub>
Purging gas	Ar
Polarity	DCEN
Welding voltage	12.9 V
Welding current	Without filler- 80A Withfiller- 100A
Travel speed	125 mm/min
Gas flowrate	Shielding gas: Ar-10 L/min N <sub>2</sub> -10 L/min Purging gas: Ar-5 L/min

**Table 3:** The resultant weld metal designations

	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-0%N <sub>2</sub>	B11	B12	B13
Ar-2%N <sub>2</sub>	B21	B22	B23
Ar-5%N <sub>2</sub>	B31	B32	B33
Ar-10%N <sub>2</sub>	B41	B42	B43

After the measurements are taken, the duplex stainless steel (2205 DSS) welds was cut to extract the center of the each welded specimen and the specimen of equal sizes were extracted. Then the extracted specimen was mounted with bakelite in a hot mounting machine. The specimens are polished with the emery from grade 60 to upto grade 1000 and polished in rough and fine disc polishing machine using alumina powder. After polishing, the specimens were colour etched using (1g Na<sub>2</sub>S<sub>2</sub>O<sub>5</sub> + 15ml HCl + 85 ml H<sub>2</sub>O) solution with an etching time of 2×12 seconds. The specimens were rinsed in ethanol in between the two 12 seconds, ethching cycle. While using 1g of sodium meta bisulphate-15 ml hydrochloric acid and 85 ml distilled water gives ferrite phase in dark and austenite phase in light (bright) colour. The rinsing in ethanol gives highest contrast between two phases. Then the specimens are over-etched to obtain macrostructure. The microstructure and macrostructure image were taken using an optical microscope.

**B. STUDIES ON THE WELD**

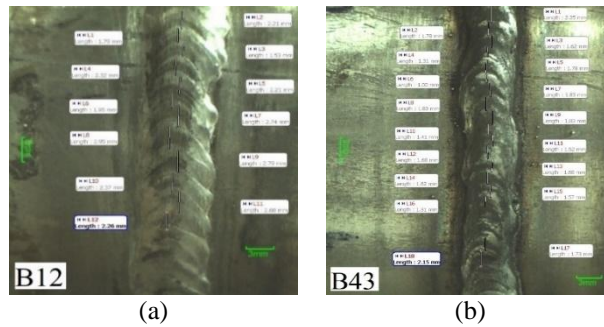
The welded samples were studied for the effect of nitrogen in argon as a shielding gas, weld bead morphology such as penetration, bead width, etc. The Vicker’s microhardness were measured on the welded samples along the transverse direction to the weld. The weld morphology were studied using a stereo microscope in which the penetration, bead width and the reinforcement was measured.

**III. EXPERIMENTAL RESULTS**

After the welding of duplex stainless steel tube, the different combination of nitrogen shielding gas and filler metals welds are examined. The present section describes the advantages of the usage of correct proportion of nitrogen gas and filler metal to obtain approximately 50:50 phase ratio after the welding.

**A. DISTANCE BETWEEN RIPPLES:**

According to the investigation of the dynamic mechanics of formation of ripples, it was noted that periodic impingement of molten weld droplets, weld pool dynamics and solidification contributed to form weld ripples on the surface of bead. In this paper the weld ripples were measured using the technique given in experimental methods. The average distance between ripples values are given in Table 4.



**Fig 5.** The measurement of the distance between ripples of different weld beads of 2205 DSS  
(a) Weld bead 12 [B12], (b) weld bead 43 [B43]

It is observed that the size of weld bead differs by various parameters, like welding process, welding current, welding speed etc.

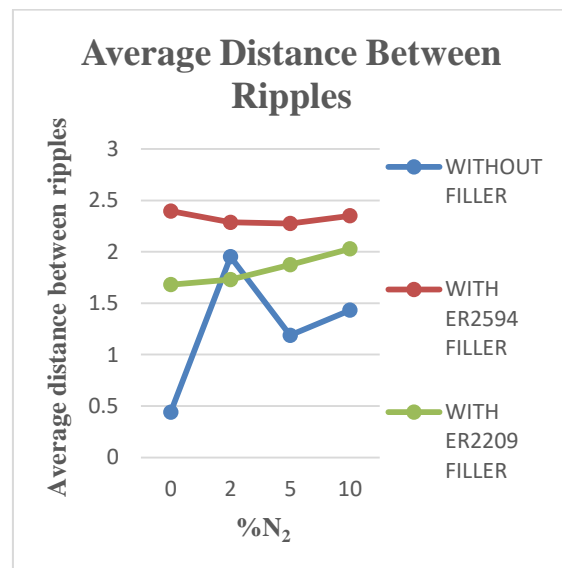
The usage of nitrogen as a shielding gas will affect the solidification of weld pool, this is due to nitrogen increases heat input during welding and thus peak temperature increases and the cooling rate will automatically reduce. If the cooling rate is decreased the time to solidifying weld metal will increase which gives uniform cooling and the proper grain structure is achieved in 50-50 phase ratio using correct combination of shielding gas and filler metal.

From the above figure 6. It was observed that during welding of DSS without filler metal, using different nitrogen level, the solidification of weld pool was erratic. While welding DSS with ER2594 Filler, the solidification of weld pool was almost same on different nitrogen level and during welding of DSS using ER2209 Filler, using different nitrogen level from 0% to 10% the ripple distance was gradually increased and the cooling rate was decreased, the time taken to solidifying weld pool increases.

From the above observation, 2% and 5% N<sub>2</sub> with ER2594 filler metal welding of DSS gives proper uniform solidification of weld pool.

**Table 4:** Average distance between the ripples (mm)

	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-0% N <sub>2</sub>	B11	B12	B13
	0.4400	2.3950	1.681
Ar-2% N <sub>2</sub>	B21	B22	B23
	1.9522	2.2857	1.7292
Ar-5% N <sub>2</sub>	B31	B32	B33
	1.1870	2.2750	1.874
Ar-10% N <sub>2</sub>	B41	B42	B43
	1.4325	2.3501	2.0285



**Fig 6.** Graph of measurement of the distance between ripples of different weld beads of 2205 DSS

**B. FERRITE CONTENT MEASUREMENT:**

The duplex stainless steel has 50-50 ferrite to austenite phase ratio gives outstanding mechanical and corrosion properties. During welding the phases may tend towards more ferritic or more austenitic or vice versa. To ensure outstanding properties it is essential to maintain ferrite-austenite ratio close to 50:50. To maintain the ferrite-austenite

ratio nitrogen shielding gas and filler metals are used. To determine the amount of ferrite content present before and after welding fisher FMP 30 feritscope is used. The feritscope measurement were done in base metal before welding and after welding at the same exact points measured before welding. This will gives the change in ferrite content before and after welding.

From the figure 7, (a) Ar-0% N<sub>2</sub>, the after weld line was at the top of the before weld line. It indicates that, while welding DSS without nitrogen shielding gas, the ferrite tends to increase in weld metal.

In the figure 7, (b) Ar-2% N<sub>2</sub>, the after weld line was slightly below the before weld line. It indicates that, while welding DSS with 2% nitrogen shielding gas the ferrite tends to decrease in weld metal, and austenite will increase. This was due to nitrogen, which is an austenite stabilizing element.

From the figure 7, (c) Ar-5% N<sub>2</sub>, the after weld line was below the before weld line. It indicates that, while welding DSS with 5% nitrogen shielding gas, the ferrite tends to decrease in weld metal and austenite will form approximately equal amount to ferrite in weld metal as the nitrogen was increased to 5% in shielding gas.

In the figure 7, (d) Ar-10% N<sub>2</sub>, the after weld line was far below the before weld line. It indicates that, while welding DSS with 10% nitrogen shielding gas the ferrite tends to decrease in a large quantity in weld metal and austenite will form more than ferrite in weld metal as the nitrogen was increased to 10% in shielding gas. While using 10% nitrogen the duplex stainless steel will tend to form more austenitic phase, this will affect the mechanical properties due to 50-50 phase ratio in duplex stainless steel was not maintained by using Ar-10% N<sub>2</sub> shielding gas mixture.

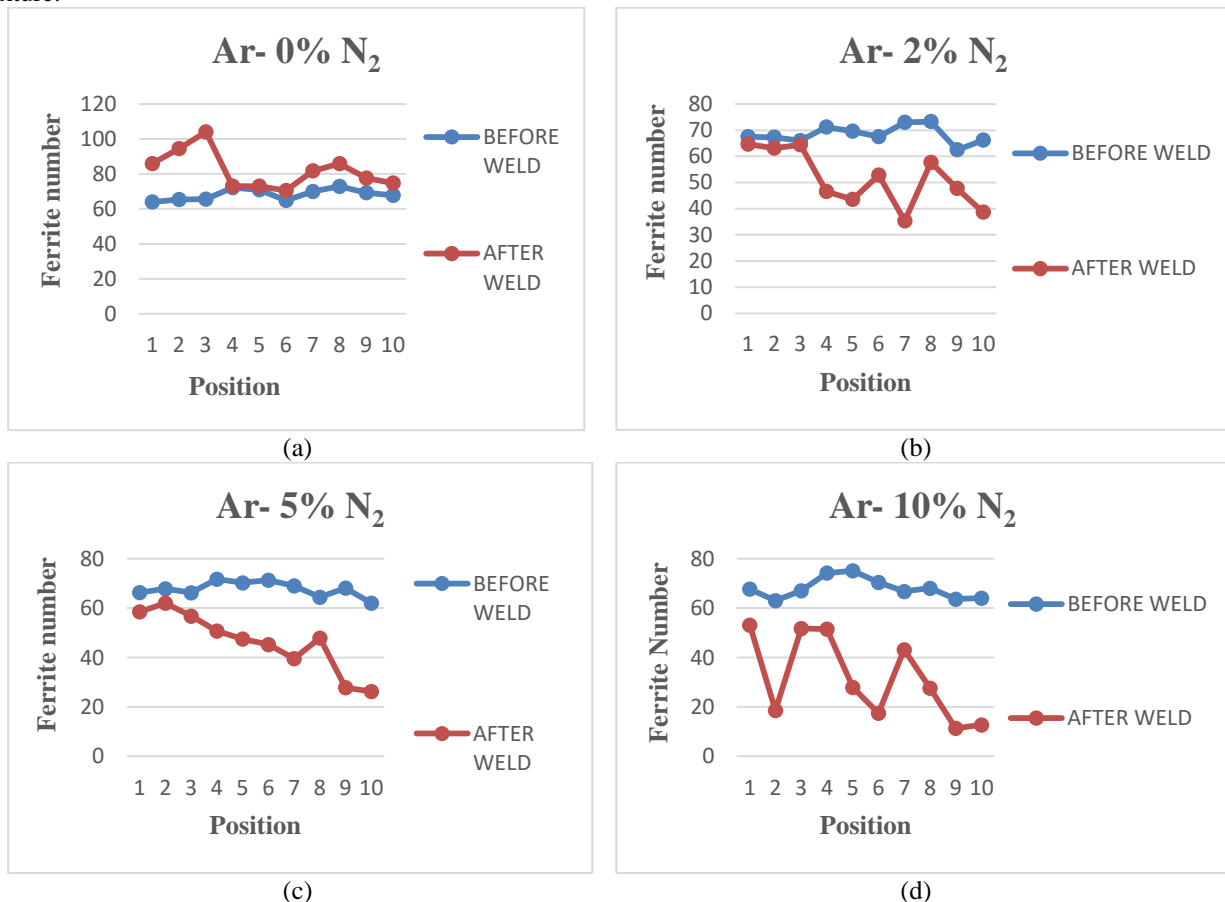
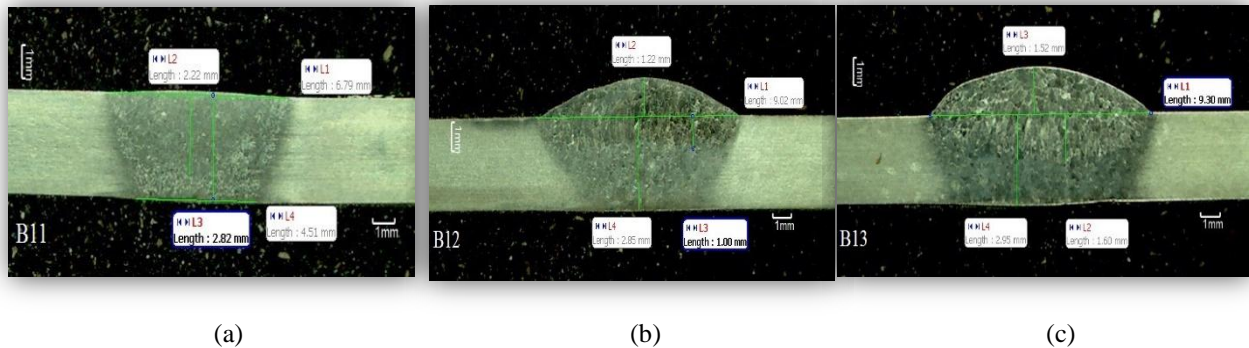


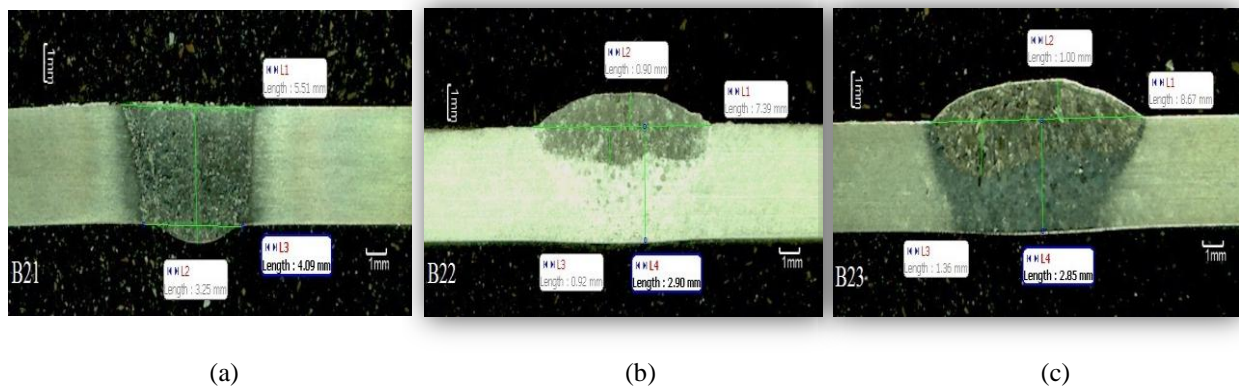
Fig 7. Graph of Change in ferrite number of 2205 DSS before weld and after weld (a) Ar-0% N<sub>2</sub>, (b) Ar-2% N<sub>2</sub>, (c) Ar-5% N<sub>2</sub>, (d) Ar-10% N<sub>2</sub>.



C. MACROSTRUCTURE EXAMINATION:



**Fig 8.** Macrostructure of DSS welded using Ar-0% N<sub>2</sub> gas  
 (a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal



**Fig 9.** Macrostructure of DSS welded using Ar-2% N<sub>2</sub> gas  
 (a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal

The macrostructure of the DSS welded region shown in figure 8, was welded without nitrogen (Ar-0% N<sub>2</sub>). In the figure 8 (a), DSS was welded without the filler metal, the weld bead structure can be easily visible that there was no reinforcement formed. On the other DSS welded regions shown in figure 8 (b) & (c), the reinforcement was formed due to use of ER2594, ER2209 filler metal. The measured values are given in table 5.

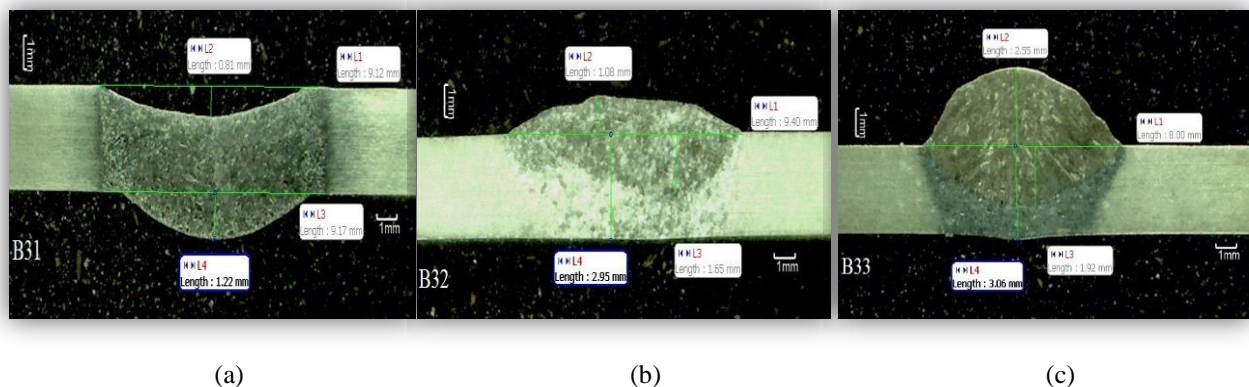
The macrostructure of the DSS welded region is shown in figure 9, was welded with 2% nitrogen. In figure 9 (a) DSS was welded without filler, the weld bead structure can be easily visible that there is no reinforcement formed and it was different from other welded regions. Figure 9 (b) & (c) the reinforcement formed was due to use of ER2594, ER2209 filler metal. The macrostructure measurements of DSS weld metal was given in table 6.

**Table 5:** The macrostructure measurements of weld metal (mm)

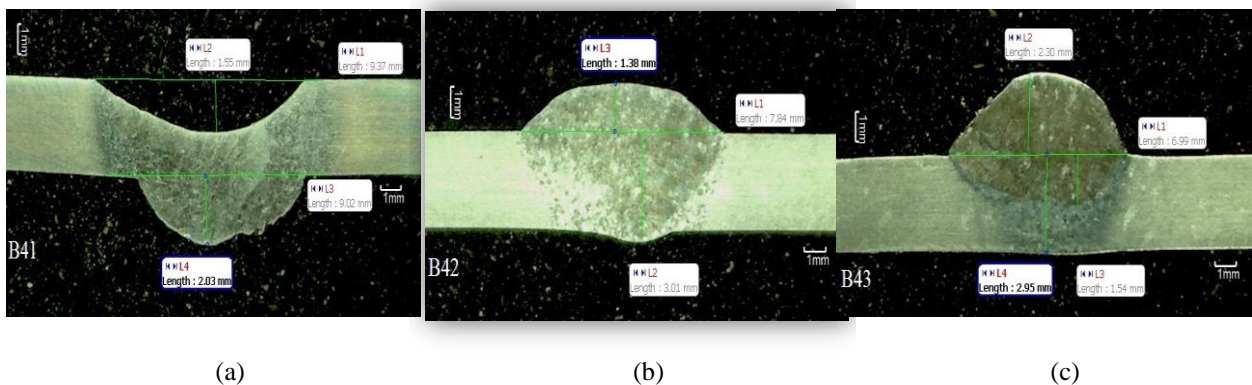
	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-0% N <sub>2</sub>	B11	B12	B13
Bead width	6.79	9	9.30
Penetration	2.82	1	1.60
Reinforcement	-	1.22	1.52

**Table 6:** The macrostructure measurements of weld metal (mm)

	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-2% N <sub>2</sub>	B21	B22	B23
Bead width	5.51	7.39	8.67
Penetration	3.25	0.92	1.36
Reinforcement	-	0.90	1



**Fig10.** Macrostructure of DSS welded using Ar-5% N<sub>2</sub> gas  
(a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal



**Fig 11.** Macrostructure of DSS welded using Ar-10% N<sub>2</sub> gas  
(a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal

The macrostructure of the DSS welded region was shown in figure 10, was welded with 5% nitrogen. In figure 10 (a) DSS was welded without filler, the weld bead structure can be easily visible that there is no reinforcement formed and it was different from other welded regions, the bead was going downwards due to increase in nitrogen content. In figure 10 (b) & (c) the reinforcement formed due to use of ER2594, ER2209 filler metal. The measured values are given in table 7.

The macrostructure of the DSS welded region is shown in figure 11, was welded with 10% nitrogen. In figure 11 (a) DSS was welded without filler, the weld bead structure can be easily visible that there is no reinforcement formed and it was different from other welded regions, the bead was going downwards than the previous 5% nitrogen shielding gas due to increase in nitrogen shielding gas content.

In figure 11 (b), (c) the reinforcement formed due to use of ER2594, ER2209 filler metal. The measured values are given in table 8 (all values are measured in mm).

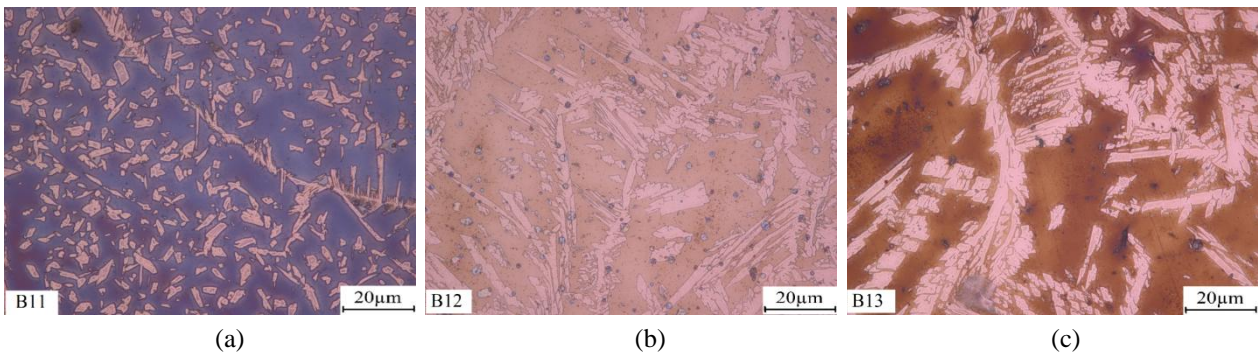
**Table 7:** The macrostructure measurements of weld metal (mm)

	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-5% N <sub>2</sub>	B31	B32	B33
Bead width	9.17	9.40	8
Penetration	-	1.65	1.92
Reinforcement	-	1.08	2.55

**Table 8:** The macrostructure measurements of weld metal (mm)

	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-10% N <sub>2</sub>	B41	B42	B43
Bead width	9.37	7.84	6.99
Penetration	-	3.01	1.54
Reinforcement	-	1.38	2.30

**D. MICROSTRUCTURE EXAMINATION:**



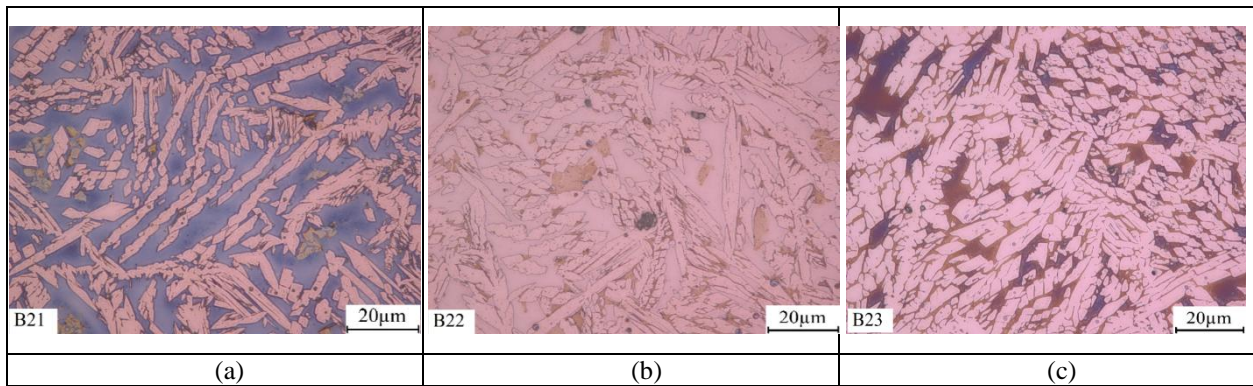
**Fig 12.** Microstructure of duplex stainless steel welded with Ar- 0% N<sub>2</sub>,  
 (a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal

The microstructure of duplex stainless steel welded with Ar-0% N<sub>2</sub> was shown in figure 12, clearly reveals austenite and ferrite phase. The bright region are austenite and dark regions are ferrite respectively.

The weld metal microstructure obtained by using different filler metal was shown in figure 12. (a, b, c), indicates the phase balance is distributed as a result of welding, resulting more in ferrite phase. In the absence of nitrogen, the cooling rate after welding will be higher resulting in higher ferrite phase after welding. This higher cooling rate restricts the ferrite to austenite transformation up on cooling to room temperature.

In the microstructure of DSS weld metal using different filler metals was shown in figure 12. (a) DSS welded without filler metal, the amount of austenite present is very low because the transformation of ferrite to austenite is restricted by higher cooling rate.

With use of ER2594 and ER2209 filler metal, shown in figure 12. (b & c), these filler metals will be having higher nickel content (austenite stabilizer), so they can have more austenite phase compared to DSS welded without filler metal, this can be easily seen in the above microstructures figure 12.

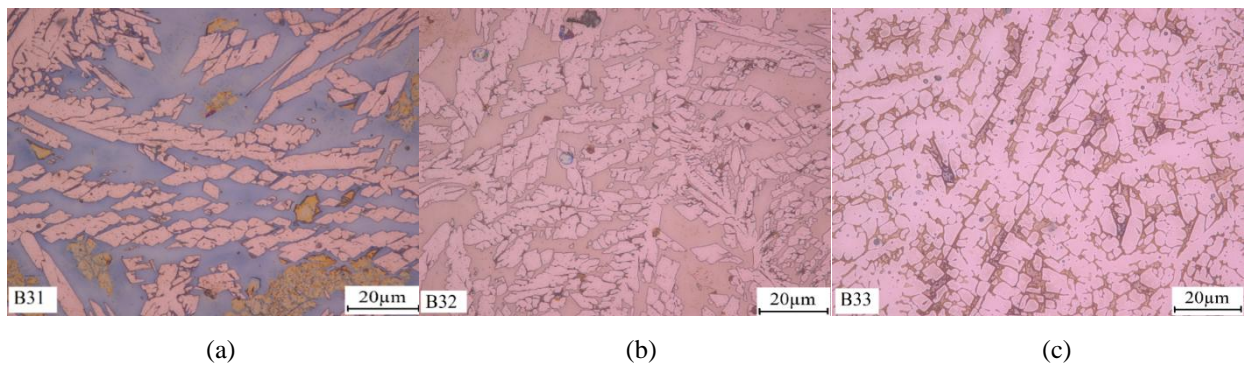


**Fig 13.** Microstructure of duplex stainless steel welded with Ar-2% N<sub>2</sub>,  
(a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal

The microstructure of duplex stainless steel welded with Ar-2% N<sub>2</sub> was shown in figure 13, clearly reveals austenite and ferrite phase. The bright region are austenite and dark regions are ferrite respectively. The weld metal microstructure obtained by using different filler metal is shown in figure 13. ( a, b, c), indicates the phase balance is distributed as a result of welding, resulting more in austenite phase than welded with Ar-0% N<sub>2</sub>.

In the presence of nitrogen, the cooling rate after welding will be comparatively slower resulting in lower ferrite phase after welding. This slower cooling rate enhances the ferrite to austenite transformation up on cooling to room temperature.

In the microstructure of DSS weld metal using different filler metals was shown in figure 13. (a) DSS welded without filler metal, the amount of austenite present is very low compared with use of ER2594 and ER2209 filler metal is shown in figure 13. (b & c). This filler metals will be having higher nickel content (austenite stabilizer) so they can have more austenite in weld metal compared to welded without filler metal, this can be easily seen in the above microstructures figure 13.



**Fig 14.** Microstructure of duplex stainless steel welded with Ar-5% N<sub>2</sub>,  
(a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal

The microstructure of duplex stainless steel welded with Ar-5% N<sub>2</sub> was shown in figure 14, clearly reveals austenite and ferrite phase. The bright region are austenite and dark regions are ferrite respectively. The weld metal microstructure obtained by using different filler metal is shown in figure 14. ( a, b, c), indicates the phase balance is distributed as a result of welding, resulting more in austenite phase than welded with Ar-0% N<sub>2</sub>, Ar-2% N<sub>2</sub>. In the presence of nitrogen, the cooling rate after welding will be slower resulting in lower ferrite phase after welding.

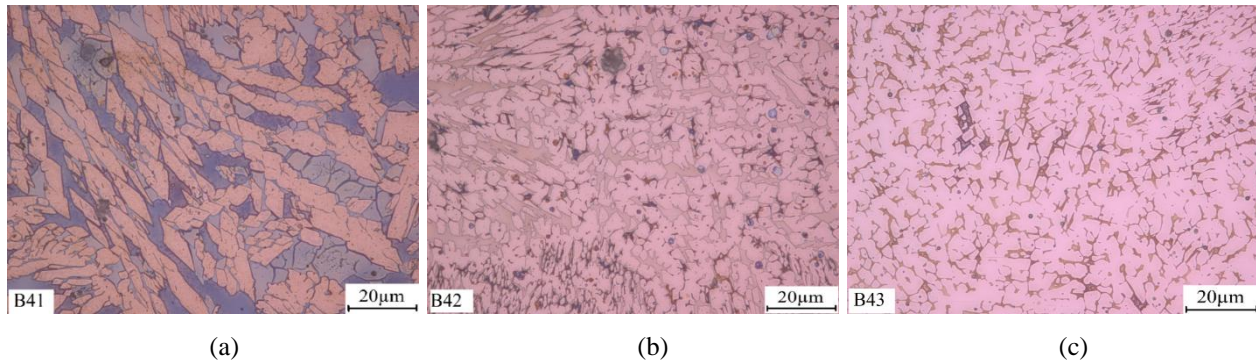
This slower cooling rate is due to higher heat input due to usage of 5% nitrogen shielding gas which enhances the ferrite to austenite transformation up on cooling to room temperature.

In the microstructure of DSS weld metal using different filler metals figure 14. (a) DSS welded without filler metal, the amount of austenite present was low compared with use of ER2594 and ER2209 filler metal is shown in figure 14. (b & c).

This filler metals will be having higher nickel content (austenite stabilizer) so they can have more austenite in weld metal compared to DSS welded without filler metal, this can be easily seen in the above microstructures figure 14.

In the microstructure of duplex stainless steel welded with Ar-5% N<sub>2</sub> shown in figure 14 has approximately 50-50 phase balance. It can be seen that while using with Ar-5% N<sub>2</sub> and ER2594 filler metal the duplex stainless

microstructure exhibits with equal amount of ferrite phase and austenite phase. This phase balance is desired one after welding of duplex stainless steel.



**Fig 15.** Microstructure of duplex stainless steel welded with Ar-10% N<sub>2</sub>,  
(a) Without filler metal, (b) With ER2594 filler metal, (c) With ER2209 filler metal

The microstructure of duplex stainless steel welded with Ar-10% N<sub>2</sub> was shown in figure 15, clearly reveals austenite and ferrite phase. The bright region are austenite and dark regions are ferrite respectively. The weld metal microstructure obtained by using different filler metal is shown in figure 15. ( a, b, c), indicates the phase balance is distributed as a result of welding, resulting more in austenite phase than welded with Ar-0% N<sub>2</sub>, Ar-2% N<sub>2</sub>, Ar-5% N<sub>2</sub>.

In the presence of nitrogen, the cooling rate after welding will be slower resulting in lower ferrite phase after welding. This slower cooling rate is due to higher heat input due to usage of 10% nitrogen shielding gas which enhances the ferrite to austenite transformation up on cooling to room temperature.

In the microstructure of DSS weld metal, using different filler metals figure 15. (a) DSS welded without filler metal the amount of austenite present is low compared with use of ER2594 and ER2209 filler metal is shown in figure 15. (b &c). This filler metals will be having higher nickel content (austenite stabilizer) so they can have more austenite in weld metal compared to welded without filler metal, this can be easily seen in the above microstructures figure 15. In this Ar-10% N<sub>2</sub> higher amount of austenite phase can be seen and with using Ar-10% N<sub>2</sub> and ER2594, ER2209 the duplex stainless microstructure will reveal fully austenite phase resembles like austenitic stainless steel. This phase balance is not a desired after welding of duplex stainless steel due to more austenite phase, this will affect mechanical properties of duplex stainless steel welds after welding and during service conditions.

#### E. VICKER'S MICROHARDNESS EXAMINATION:

The microhardnesses across the weld metal of the Duplex Stainless Steel is shown in figure 16. The different zones of the Duplex Stainless Steel weld joint had different hardnesses. The weld metals using different level of nitrogen shielding gas exhibited the highest hardnesses are shown in table 9, while the base metal had the lowest hardness (average value: 246.33 HV). The hardness of the weld metal was significantly higher than that of the base metal. The Ar-5% N<sub>2</sub> shielding gas and ER2594 had given hardness value (average value 265.5 HV).



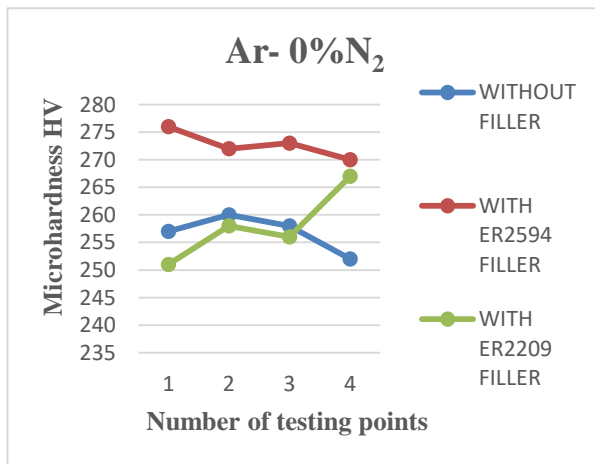
**Table 9:** Microhardness of the weld metals(HV)

	Without filler metal	With ER2594 filler metal	With ER2209 filler metal
Ar-0% N <sub>2</sub>	B11	B12	B13
	256.75	272.75	258
Ar-2% N <sub>2</sub>	B21	B22	B23
	264.5	282.25	255.25
Ar-5% N <sub>2</sub>	B31	B32	B33
	264	265.75	239.25
Ar-10% N <sub>2</sub>	B41	B42	B43
	252.75	263	265.5

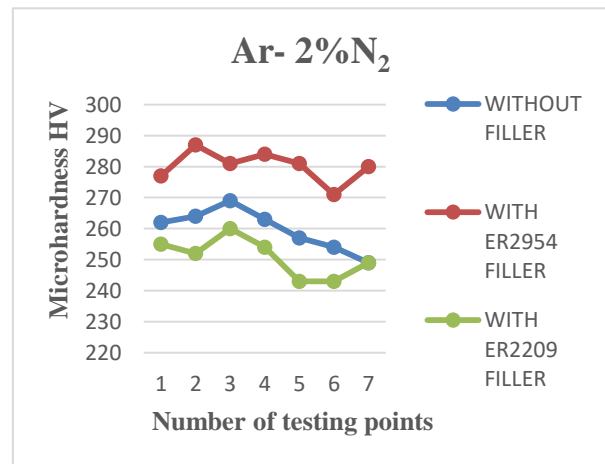
There are four main factors that determine the hardness of the Duplex Stainless Steel:

(a) The first factor is the solid-solution content of nitrogen within the austenite. Generally, more nitrogen solid solution in the austenite would result in a higher hardness due to solution strengthening.

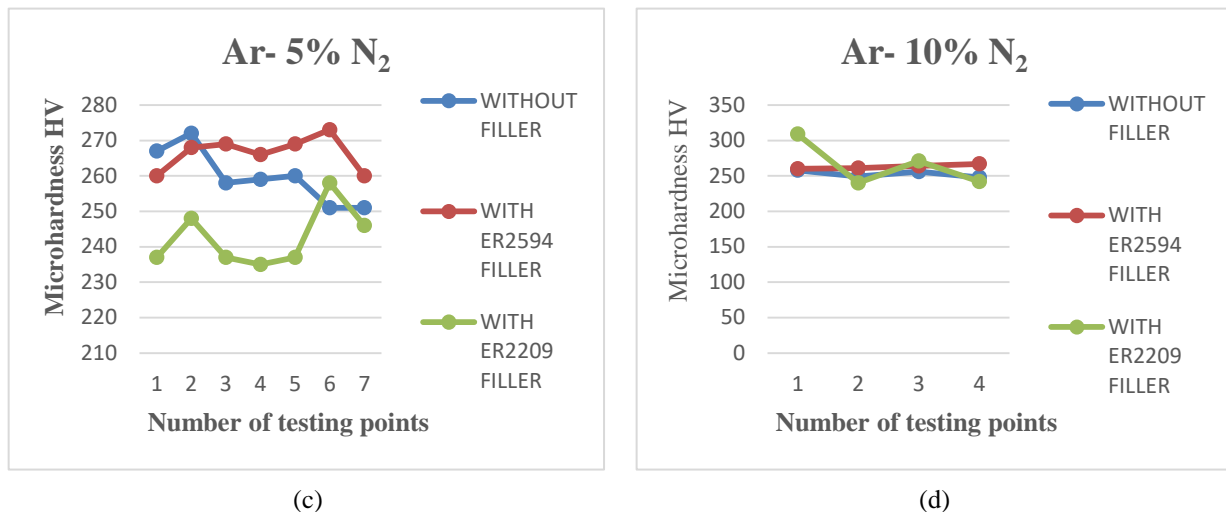
(b) The second factor is the precipitation of hard secondary phases such as, nitrides, and carbides, which can significantly increase the hardness of the DSS. However, these hard and brittle secondary precipitates impaired the corrosion resistance and toughness of the DSS, as reported by the authors [11].



(a)



(b)



**Fig 16.** Microhardness of duplex stainless steel welded with different level of nitrogen shielding gas  
(a) Ar-0% N<sub>2</sub>, (b) Ar-2% N<sub>2</sub>, (c) Ar-5% N<sub>2</sub>, (d) Ar-10% N<sub>2</sub>

(b) The second factor is the precipitation of hard secondary phases such as, nitrides, and carbides, which can significantly increase the hardness of the DSS. However, these hard and brittle secondary precipitates impaired the corrosion resistance and toughness of the DSS, as reported by the authors [11].

(c) The third factor is the ferrite content (which also includes the ferrite grain size). The ferrite phase is generally regarded as a strengthening phase [13].

(d) The fourth factor is the relative frequency of deformed austenite grains. Generally, austenite is regarded as a ductile phase, as compared to ferrite. The deformed austenite grains result in local deformations and a large amount of dislocation multiplication. The increase in dislocation density increases the hardness. Therefore, the increase in the deformed austenite grains can increase the hardness of the microstructure. Furthermore, the Weld metal contained more deformed austenite grains compared to the base metal, which may be one of important factors that result in a higher hardness than that found in the base metal.

#### IV. CONCLUSION

This study gives an outstanding part of nitrogen as a shielding gas in argon gas mixture along with usage of ER2594, ER2209 filler metals in welding for duplex stainless steel to maintain phase balance of approximately 50-50 ratio of ferrite and austenite. Some of the important observation of this study is as follows.

1. The usage of nitrogen as a shielding gas will affect the solidification of weld pool, this is due to nitrogen increases heat input during welding and thus peak temperature increases and the cooling rate will automatically reduce. From the above observation Ar-5% N<sub>2</sub> and Ar-5% N<sub>2</sub> with ER2594 filler metal gives proper uniform solidification of weld pool.
2. The magnetic induction based Feritscopes are mainly used for phase ratio quantification. The used instrument was a Fischer FMP 30 Feritscope This gives details regarding the amount of ferrite number changing before and after welding. It was observed that, while welding with 5% nitrogen shielding gas the ferrite tends to decrease in weld metal and austenite would form approximately equal amount to ferrite in weld maintaining 50-50 phase ratio and while welding with 10% nitrogen shielding gas the ferrite tends to decrease in weld metal almost completely and austenite phase present in maximum and resembles like austenitic stainless steel structure.
3. The weld bead formed in different shapes while welding and upon using different level of nitrogen gas and filler metals, those macrostructure was taken using a stereo microscope. The weld bead characteristics like penetration, reinforcement and bead with are measured and those macrostructures formed are due to different level of nitrogen gas and filler metal used.
4. The increase in nitrogen content in shielding gas mixture would tend to increase nitrogen content and austenite phase in weld metal was clearly observed in microstructures of weld metal. Welding without nitrogen shielding gas causes increase in ferrite content in weld metal. The phase balance maintained by using Ar-5% N<sub>2</sub> gas mixture.
5. The weld metal exhibited the highest hardness, while the BM had the lowest hardness. The welding of duplex stainless steel using nitrogen shielding gas and filler metals will tend to form most austenite phase which has very less hardness, so the combination of Ar-5% N<sub>2</sub> gas mixture with ER2594 filler metal gives hardness of approximate hardness of 50-50 phase balance duplex stainless steel.

#### ACKNOWLEDGMENT

The authors thankfully acknowledge the Welding Research Institute (WRI), BHEL, Trichy, for carrying out the welding trials

#### REFERENCES

- [1] A. Igual Muñoz, J. García Antón, J.L. Guiñón, V. Pérez Herranz, “Effect of Nitrogen in Argon as a Shielding Gas on Tungsten Inert Gas Welds of Duplex Stainless Steels” CORROSION—Vol. 61, No. 7, July 2005.
- [2] V. Muthupandi, P. Bala Srinivasan, S. K. Seshadri and S. Sundaresan, “Effect of nitrogen addition on formation of secondary austenite in duplex stainless steel weld metals and resultant properties” Science and Technology of Welding and Joining Vol. 9 No. 1, 2004.
- [3] Balázs Varbai, Timothy Pickle, Kornél Májlinger, “Development and Comparison of Quantitative Phase Analysis for Duplex Stainless Steel Weld” Phase Quantification in Duplex Steels Vol.62, No.3, 2018.
- [4] Balázs Varbai, Timothy Pickle, Kornél Májlinger, “Effect of heat input and role of nitrogen on the phase evolution of 2205 duplex stainless steel weldment” International Journal of Pressure Vessels and Piping, 2019.
- [5] L. Claeys, T. Depover, I. De Graeve, K. Verbeke “First observation by EBSD of martensitic transformations due to hydrogen presence during straining of duplex stainless steel” Materials Characterization 156 109843, 2019.
- [6] P. Kah, J. Martikainen “Influence of shielding gases in the welding of metals” Int J Adv Manuf Technol 64:1411–1421, 2013.
- [7] V. Muthupandi, P. Bala Srinivasan, S. K. Seshadri S. Sundaresan “Corrosion behaviour of duplex stainless steel weldmetals with nitrogen additions” Corrosion Engineering, Science and Technology Vol. 38 No. 4, 2003.
- [8] Ping Yao, Kang Zhou, Heqing Tang, “Effects of Operational Parameters on the Characteristics of Ripples in Double-Pulsed GMAW Process” Materials, MDPI, 2019.
- [9] Balázs Varbai and Kornél Májlinger “Physical and Theoretical Modeling of the Nitrogen Content of Duplex Stainless Steel Weld Metal: Shielding Gas Composition and Heat Input Effects” Metals, 9, 762, 2019.
- [10] Zhiqiang Zhang,, Hongyang Jing, Lianyong Xua,, Yongdian Han, Zhanqi Gao, Lei Zhao, Jianli Zhang, “Microstructural characterization and electron backscatter diffraction analysis across the welded interface of duplex stainless steel” Applied Surface Science 413, 327–343, 2017.
- [11] Z.Q. Zhang, H.Y. Jing, L.Y. Xu, Y.D. Han, L. Zhao, “Investigation on microstructure evolution and properties of duplex stainless steel joint multi-pass welded by using different methods” Mater. Des. 109, 670–685, 2016.
- [12] Chern T-S, Tseng K-H, Tsai H-L, “Study of the characteristics of duplex stainless steel activated tungsten inert gas welds” Mater Des 32(1):255–263, 2011.
- [13] E. Guo, H. Xie, S.S. Singh, A. Kirubanandham, T. Jing, N. Chawla, “Mechanical characterization of microconstituents in a cast duplex stainless steel by micropillar compression” Mater. Sci. Eng. A 598, 98–105, 2014.
- [14] Sathya P, Aravindan S, Soundararajan R, Noorul Haq A, “Effect of shielding gases on mechanical and metallurgical properties of duplex stainless steel welds” J Mater Sci, 44(1):114–121, 2009.





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