

Article

The Effects of Nitrogen Gas on Microstructural and Mechanical Properties of TIG Welded S32205 Duplex Stainless Steel

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Abstract: Duplex stainless steels are gaining greater interest due to their increasing amounts of application fields. Accordingly, there is a need for awareness of problems associated with improper microstructural distributions such as δ -ferrite (delta-ferrite), austenite and other important intermetallic phases that may form in these steel weldments. Since δ -ferrite versus austenite ratio profoundly influences corrosion and mechanical properties, optimum δ -ferrite ratios must be kept approximately within 35–65 vol % and balance austenite to maintain satisfactory corrosion and mechanical properties on welding of these steels. Cooling rates of welds and alloying elements in base metal are the major factors that determine the final microstructure of these steels. In this work, 3 mm thickness of 2205 duplex stainless-steel plates were TIG (Tungsten Inert Gas) welded with various amounts of nitrogen gas added to argon shielding gas. Specimens were joined within the same welding parameters and cooling conditions. As nitrogen is a potential austenite stabilizer and an interstitial solid solution hardener, the effects of nitrogen on mechanical properties such as hardness profiles, grain sizes and microstructural modifications are investigated thoroughly by changing the welding shielding gas compositions. Increasing the nitrogen content in argon shielding gas also increases the amount of austenitic phase while δ -ferrite ratios decreases. Nitrogen spheroidized the grains of austenitic structure much more than observed in δ -ferrite. The strength values of specimens that welded with the addition of nitrogen gas into the argon shielding gas are increased more in both austenitic and delta-ferritic structure as compared to specimens that welded with plain argon shielding gas. The addition of 1 vol % of nitrogen gas into argon shielding gas provided the optimum phase balance of austenite and δ -ferrite in S32205 duplex stainless-steel TIG-welded specimens.

Keywords: duplex stainless steels; TIG welding; nitrogen gas effects

1. Introduction

The development and the use of duplex alloys started in the 1970s as a consequence of a nickel shortage that increased the price of austenitic alloys. Steel production techniques then improved dramatically with the introduction of vacuum and argon decarburization (VOD, AOD) practices. These techniques led to steels with simultaneously low carbon, sulfur and oxygen contents etc. while allowing for greater control of composition, especially nitrogen [1].

Nitrogen usually presents as an impurity in many stainless steels. Nitrogen is an intentional addition to some of the austenitic and almost all the duplex grades. Similar to carbon, nitrogen is a powerful solid solution strengthening agent, and additions of as little as 0.15 wt % can dramatically increase the strength of austenitic alloys [1]. Authors declared that nitrogen is added to duplex

stainless steels for improving strength but, more importantly, to increase resistance to pitting and crevice corrosion [2–4]. Some duplex alloys contain up to 0.3 wt % nitrogen. The solubility of nitrogen in stainless steels is very low, particularly in ferrite phase. In ferritic and duplex grades, Cr_2N will precipitate in the ferrite phase if the solubility limit is exceeded as can be seen in weld metals and heat-affected zones (HAZ) of these alloys, if appreciable austenite falls to form during cooling from temperatures above about 1100 °C. Nitrogen is added to argon shielding gas in duplex stainless-steel welds to preserve weld metal nitrogen levels [2]. During welding, carbon and nitrogen completely dissolves in the fusion zone and regions of HAZ are heated above approximately 1100 °C depending on the heating rate [2,5]. Upon cooling, Cr-rich Cr_{23}C_6 and Cr_2N may precipitate at either inter- or intra-granular sites of duplex stainless steels [2,6]. δ -ferrite versus austenite ratio influences the corrosion and mechanical properties; hence optimum δ -ferrite ratios must be kept approximately within 35–65% by volume to ensure satisfactory environmental corrosion resistance and adequate mechanical properties on welding of these steels. [1,2].

Various authors mentioned and studied nitrogen's multiple effects on stainless steels by increasing pitting resistance, austenite content and strength [1,2,7–13]. Nitrogen partitions preferentially to the austenite due to the increased solubility in the austenite phase and also concentrates at the metal-passive film interface. Nitrogen has also been noted to increase the crevice corrosion resistance. Nitrogen alters the crevice solution chemistry or segregates to the surface, which is in keeping with the mechanism for enhanced pitting resistance [1,2].

The addition of C and N strengthens both ferrite and austenite by dissolving at interstitial sites in the solid solution. Furthermore, raising the nitrogen content preferentially strengthens the austenite by interstitial solid solution hardening to the point where it becomes stronger than the ferrite. For low nitrogen contents (<0.1%) the austenite has the lower yield strength while at higher levels (>0.2%) the ferrite becomes the weaker phase [1,14]. As large amounts of carbon is undesirable in stainless steels, due to the risk of sensitization, the addition of nitrogen is preferred. Nitrogen is a strong austenite stabilizer, therefore addition of nitrogen to duplex stainless steel suppresses austenite dissolution and enhances austenite reformation in the HAZ [1]. Nitrogen enhances the corrosion resistance of austenitic structure but without nitrogen the corroded structure is ferrite in duplex stainless steels [15]. The higher cooling rate leads to the higher amount of chromium nitrides in duplex stainless steels [1,2]. Consequently, cooling rate and chemical situations of both duplex structure and shielding gas composition is strongly affecting the final micro constituents in duplex stainless-steel weldments.

In this work, the effects of nitrogen gas amount in argon shielding gas on microstructural and mechanical properties of 3 mm thickness S32205 duplex stainless-steel plates that are joined by TIG welding are studied. ASTM A 923 [16] standard is used for microstructural studies. The amounts of phases were evaluated by magnetic Ferritemeter, and microstructural phase (image) analysis is also applied for phase distributions.

2. Materials and Methods

The experimental investigation concerns the nitrogen gas effects on microstructural developments and microhardness values in manual TIG welding.

The chemical compositions of type S32205 (2205) duplex stainless steel plate and the W22 9 3 NL, (ER 2209) TIG welding rods are both given in Table 1.

Table 1. Chemical composition (spectral analysis) of Duplex 2205 stainless steel plates and (production analysis) of W22 9 3 NL (ER 2209) TIG welding rods (wt %).

Material	C	Mn	P	S	Si	Cr	Ni	Mo	Fe	N	Others
2205 duplex stainless steel composition	0.031	0.832	0.024	0.004	0.423	24.957	6.638	3.511	62.10	0.306	1.174
W22 9 3 NL, (ER 2209) TIG welding rods composition	0.01	1.50	0.02	0.001	0.440	23.0	8.60	3.1	62.06	0.16	1.109

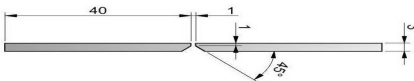
Spectral analysis is applied by Spectromax Argon Optical Emission Spectrometer (Spectro Ametek, Kleve, Germany). Samples were TIG-welded in five different gas mixtures of shielding gases to change the ratios of δ -ferrite versus austenite as shown in Table 2. Three samples per each shielding gas circumstance are welded. Unwelded base metal is also investigated for comparison with the weldments.

Table 2. Specimens and welding shielding gasses.

Specimen	Welding Shielding Gas (by Volume)
Base Metal	Unwelded
A	Pure Argon
B	Ar + 1% N ₂
C	Ar + 3% N ₂
D	Ar + 6% N ₂
E	Ar + 9% N ₂

TIG welding parameters are shown in Table 3. TIG welding is applied within two passes.

Table 3. Welding parameters.

Shielding Gas	Shielding Gas Flow (L/min)	Welding Speed (mm/s)		Welding Current DC (–) Non-Pulsed (Amperes)		Welding Voltage (Volts)	
		Root Pass	Second (Final) Pass	Root Pass	Second (Final) Pass	Root Pass	Second (Final) Pass
0%, 1%, 3%, 6%, 9% N ₂ -remainders of argon gases	6 L/min	2.16	2.13	75A	100A	12V	13V
Weldment preparation							

AWS EWTh-2 (WT-20) Thorium alloyed TIG electrode is used in welding operations. An electrode tip is prepared with a 30° angle and the total length of the arc is maintained approximately at 16 mm. All samples are joined with ceramic backing from the root side. As soon as the welding operation finishes, the welded specimens are immediately and calmly cooled in a 25 °C fresh water tank for ensuring the same cooling conditions of weldments.

Microstructural investigation was made to define the aspects of various shielding gas composition effects on the microstructural developments according to ASTM A923 by Leica metallurgical microscope that has capability of 1200× magnification. The samples are ground with 240 to 600 emery papers and polished with a 3 µm polisher. Samples are electrolytically-etched with NaOH solution as indicated in literature [17].

Image analysis was applied according to ASTM E562 [18], ASTM E1245 [19] standards to determine the phases ratios by Leica metallurgical microscope. Image analysis was performed by licensed Kameram and Metalim software on all specimens.

As ferrite is a magnetic phase and austenite is not, magnetic testing of phase analysis is also applied within ISO 8249 [20], EN ISO 17655 [21], AWS A4.2 [22] standards for verifying the image analysis results. Six individual magnetic tests are applied on each specimen by Ferrite tester SP10-a gauge onto 6 points in the center line of the weld metal throughout a straight line and the arithmetic average single value is estimated as noticed in EN ISO 17655 standard. Ferrite tester SP10-a instrument has an accuracy of ±3% up to 80% δ -ferrite amounts.

The effects of nitrogen content on grain sizes of phases is determined by Kameram software with a Leica metallurgical microscope according to ASTM E112 [23] standard. The grain size estimation of δ -ferrite and austenite phases are observed separately.

Hardness profiles were examined by an Emcotest Durascan 20 model microvickers micro-hardness testing instrument that is capable of a HV10 g–10 kg load capacity. Austenite and δ -ferrite hardness values are observed separately by HV_{0.3} microvickers hardness testing in 500 $\times$ magnification conditions.

The grain size evaluation of all specimens according to ASTM E112 standard is applied by Kameram software (Version-122, Mikro-Sistem, Image Analysis, Istanbul, Turkey). The grain size estimation module of the software is applied on specimen micrographs.

3. Results

3.1. Microstructural Investigation of Base Metal

Figure 1 shows the micrographs of base (unwelded) metal.

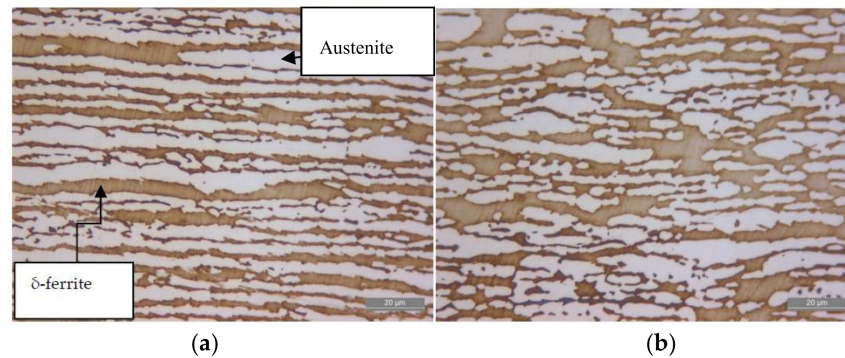


Figure 1. Base metal (unwelded specimen) microstructures (a) longitudinal (b) transverse direction (500 $\times$).

As obviously seen from Figure 1, base metal consists of the two main dominant phases that the brown (dark phase) is δ -ferrite and the white (lighter phase) is austenite. The wrought structure reveals the straight rolling direction of duplex stainless steel in Figure 1a longitudinal and Figure 1b transverse directions. The rolling direction of wrought 2205 metal is perpendicular to the weld axis. The unwelded base metal consists of approximately 54% δ -ferrite and 46% austenite by volume from phase (image) analysis and estimated by magnetic Ferritemeter results.

3.2. Determination of Phases by Microstructural and Magnetic Methods

The image analysis of the specimen welded with pure argon shielding gas is given as an example below in Figure 2.

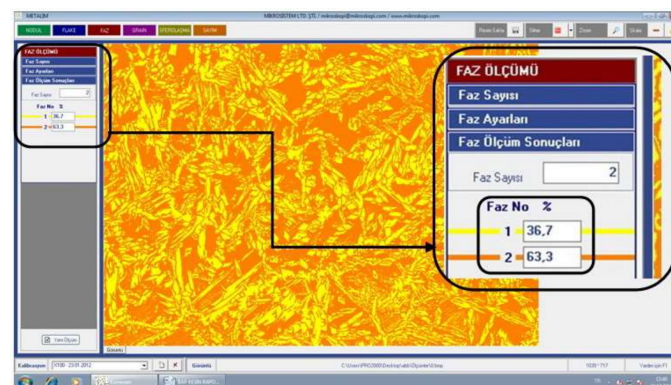


Figure 2. Image analysis of specimen welded with pure argon shielding gas (Specimen A), orange: δ -ferrite 63.3%, yellow: austenite 36.7%.

Magnetic and microstructural phase analysis results of base metal and five weldments are listed in Table 4 for comparison.

Table 4. Magnetic and microstructural phase analysis results of base metal and five weldments.

Specimen	Welding Shielding Gas	Image Analysis by vol % Mean Values of 3 Individual Estimation (ASTM E562, ASTM E1245)		Magnetic % δ -Ferrite Analysis by 6 Individual Points and Mean Values in vol % (Ferritester-ISO 8249 ANSI/AWS A4.2-EN ISO 17655)							
		δ -Ferrite/Std. Dev.	Austenite/Std. Dev.	1	2	3	4	5	6	Std. Dev.	Mean Value
Base metal	Unwelded	54/0.577	46/0.816	53.8	53.6	55.5	55.9	56.1	56.7	1.275	55
A	Pure Argon	63.3/0.173	36.7/1.214	61.6	61.9	64.0	61.3	62.3	61.9	0.958	62
B	Ar+1% N ₂	54.2/0.816	45.8/0.721	52.4	51.1	54.4	53.2	54.3	53.9	1.279	53
C	Ar+3% N ₂	55.6/0.529	44.4/1.039	53.9	54.9	50.9	46.9	51.3	48.7	3.025	51
D	Ar+6% N ₂	36.5/0.866	63.5/0.866	36.2	36.2	36.1	35.4	36.7	39.5	1.441	37
E	Ar+9% N ₂	33.8/0.721	66.2/0.346	32.6	33.6	34.4	34.2	33.0	33.7	0.688	34

Std. Dev.: Standard Deviation.

As can be seen from Table 4 and graphic illustration by Figure 3, if the amount of nitrogen gas in argon shielding gas increases, austenite phase rate also increases, while δ -ferrite ratio decreases.

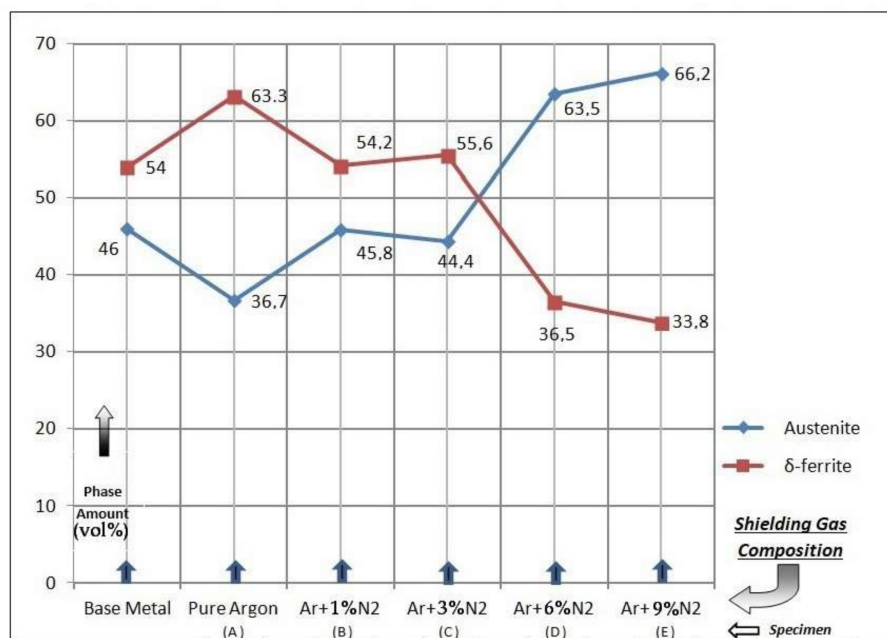


Figure 3. The effect of shielding gas composition on phase percentage distributions.

Increasing amounts of nitrogen gas accelerates the formation of austenite and stabilizes it [1,2,5].

3.3. Microstructural Investigation of Weldments

All the weldment micrographs are shown in Figures 4–8. Similar to base metal, the brown (darker) phase is δ -ferrite and the white (lighter) phase is austenite in weldments. Micrographs are consistent with the literature [1,2,17,24,25].

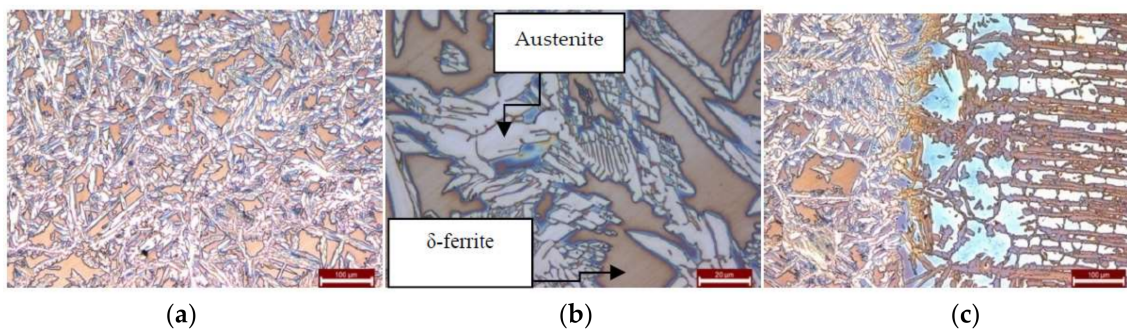


Figure 4. Micrographs of specimen A joined by pure argon shielding gas (a) weld metal 100 $\times$ (b) weld metal 500 $\times$ (c) heat effected zone (HAZ) 100 $\times$.

The weld metal of the joint welded with pure argon gas is shown in Figure 4a,b. Microstructure consists of 63% δ -ferrite and 37% austenite from phase analysis. The white (lighter) phase is austenite and the brown (darker) phase is δ -ferrite. The result is obtained as a consequence of increasing cooling rate by welding operation against base metal.

Meanwhile, base metal wrought structure is affected from heat source of welding; in other words, when getting closer to the heat-affected zone (HAZ) from base metal, δ -ferrite grains conglomerate, and the regular wrought structure transforms into coarse grains as shown in Figure 4c.

Chemical composition of duplex stainless steel, welding wire, shielding gas content, and cooling rate significantly determine the distribution of phases in welding [1,2]. Therefore, the final microstructure is essentially established by the majority of shielding gas content in this study.

The weld metal of the joint welded with by Ar + 1% N₂ is shown in Figure 5.

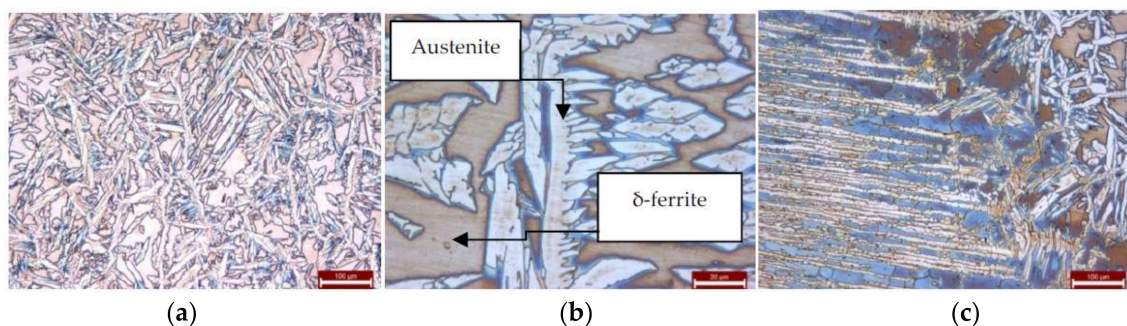


Figure 5. Micrographs of weldments by Ar + 1% N₂ shielding gas (a) weld metal 100 $\times$ (b) weld metal 500 $\times$ (c) HAZ 100 $\times$.

Because nitrogen is a strong austenite stabilizer, the amount of δ -ferrite in weld metal reduces to 54.2% by adding 1% N₂ gas into argon shielding gas as compared with pure argon (63.3% δ -ferrite) welded specimen. There have been no considerable changes to the microstructural point of view by adding 1% N₂ gas into the argon shielding gas due to insufficient amounts of nitrogen in the welding operation and therefore the solubility limit of nitrogen in ferrite and austenite is not yet exceeded, which is shown in Figure 5a,b as well agreed with the literature [2].

Micrographs of weldments that joined by Ar + 3% N₂ shielding gas are given in Figure 6 below. In the same manner as Figure 5, no significant shift in microstructure happened in Figure 6a,b but δ -ferrite grains picked up together and austenite grains conserve themselves while getting closer into the HAZ in Figure 6c. The amount of δ -ferrite in weld metal increases to 55.6% by adding 3% N₂ gas in argon shielding gas.

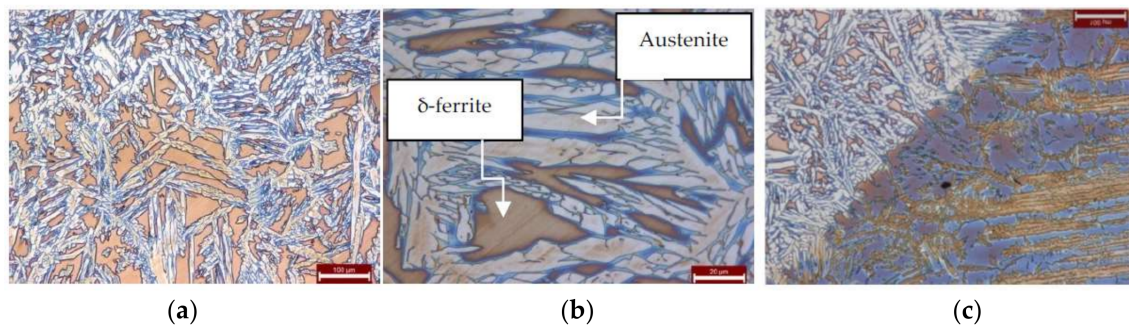


Figure 6. Micrographs of weldments joined by Ar + 3% N₂ shielding gas (a) weld metal 100× (b) weld metal 500× (c) HAZ 100×.

Micrographs of weldments joined by Ar + 6% N₂ shielding gas is given in Figure 7. Ar + 6% N₂ shielding gas composition not only effects the general appearance of microstructure but also lessens the quantity of δ-ferrite to 36.5 vol %. Solidification concluded as spherodized and corn-on-the-cob-like austenite. δ-ferrite is oriented through the austenite grain boundaries and followed the thermal gradient by welding. Increasing nitrogen gas increased the austenite ratio up to 63.5 vol %.

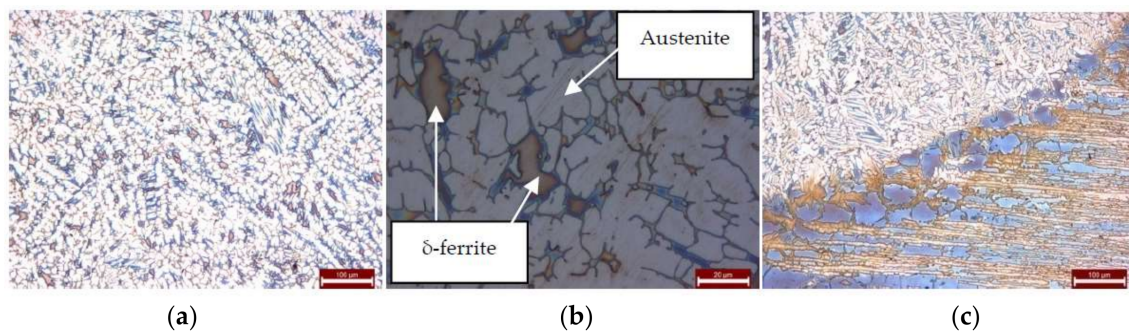


Figure 7. Micrographs of weldments by Ar + 6% N₂ shielding gas (a) weld metal 100× (b) weld metal 500× (c) HAZ 100×.

The specimen welded by 9% nitrogen gas addition into argon shielding gas gave the weldment the highest austenite (66.2%) and the lowest amount of δ-ferrite (33.8) values in volume; the micrograph is given in Figure 8. The majority of weld metal is in austenitic microstructure in this case. δ-ferrite exists within austenite grains and exhibits greater grain sizes in HAZ rather than in weld metal shown in Figure 8a–c.

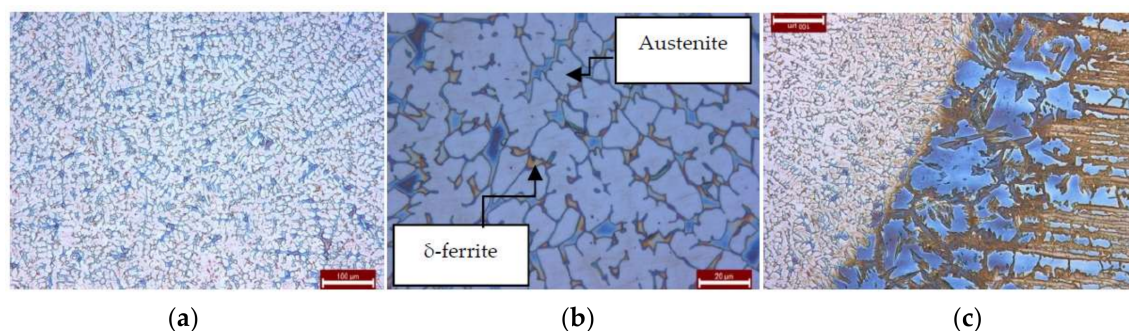


Figure 8. Micrographs of weldments by Ar + 9% N₂ shielding gas (a) weld metal 100× (b) weld metal 500× (c) HAZ 100×.

Microstructures are prepared on weld metal and HAZ according to the ASTM A923 standard [16].

3.4. Determination of Grain-Sizes of Phases According to ASTM E 112 by Kameram Software

Unwelded base metal and the specimen that TIG welded by pure argon δ -ferrite grain size result screens are shown as examples in Figure 9 below.

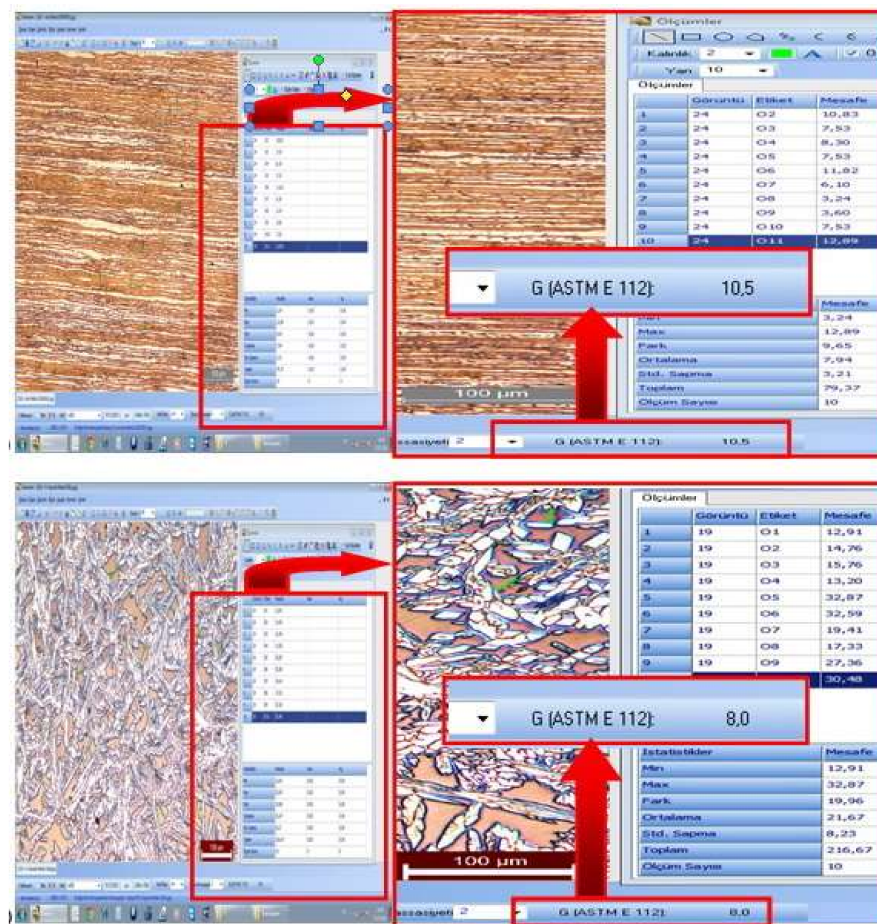


Figure 9. Determination of δ -ferrite phase grain size; upper figure: base metal ASTM 10.5, bottom figure: specimen welded with pure argon shielding gas, ASTM 8.0.

The grain size evaluations of all specimens according to ASTM E112 standard by Kameram Software are shown in Table 5.

Table 5. Grain sizes of all specimen.

Specimen	Status	Phase Ratios %		ASTM No. Grain Sizes of Phases-ASTM E 112			
		δ -Ferrite	Austenite	Austenite	μm	δ -Ferrite	μm
Base Metal	Unwelded	55.0	45.0	10.5	8.14	10.5	7.94
A	Pure Argon	63.3	37.7	10.5	8.15	8.0	21.67
B	Ar + 1% N ₂	54.2	46.8	8.5	15.60	7.0	26.70
C	Ar + 3% N ₂	55.6	44.4	8.5	15.63	7.0	27.48
D	Ar + 6% N ₂	36.5	64.5	9.5	12.70	10.5	8.35
E	Ar + 9% N ₂	33.8	67.2	9.5	13.63	11.5	6.06

As seen from Table 5 and schematically illustrated in Figure 10, austenite and δ -ferrite has the same grain size at the beginning in base metal, but as the nitrogen gas increases in the argon shielding

gas, both austenite and δ -ferrite grain size gets coarser up to 6% N_2 . When the nitrogen amount reaches 6%, the grain size returns to the original state observed in base metal.

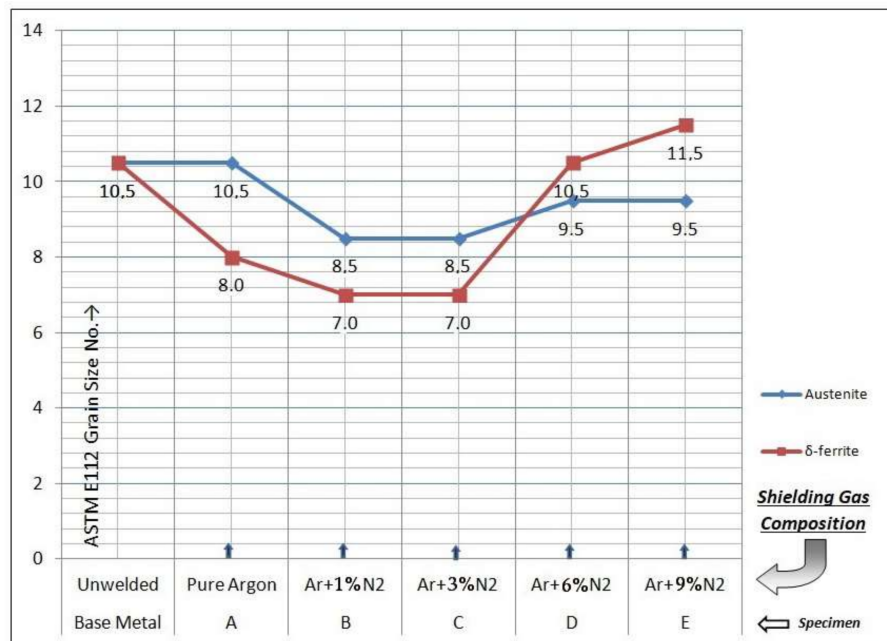


Figure 10. The effects shielding gas composition on phases grain size.

3.5. Micro-Hardness Profiles

Hardness profiles are given in Figure 11 as examples applied on weld metals. Austenite and δ -ferrite hardness values are observed by $HV_{0.3}$ microvickers hardness testing.

Unwelded base metal has approximately the same microvickers hardness values for austenite and δ -ferrite while the equilibrium changes on welding starting from the sample that joined with pure argon shielding gas. When nitrogen gas is added to about 1 vol % in argon shielding gas as seen in in Table 6, the weldment gains a peak hardness value. Hence, greater N_2 gas amounts results in decreasing hardness values compared to the specimen that was welded with 1 vol % N_2 in argon shielding gas.

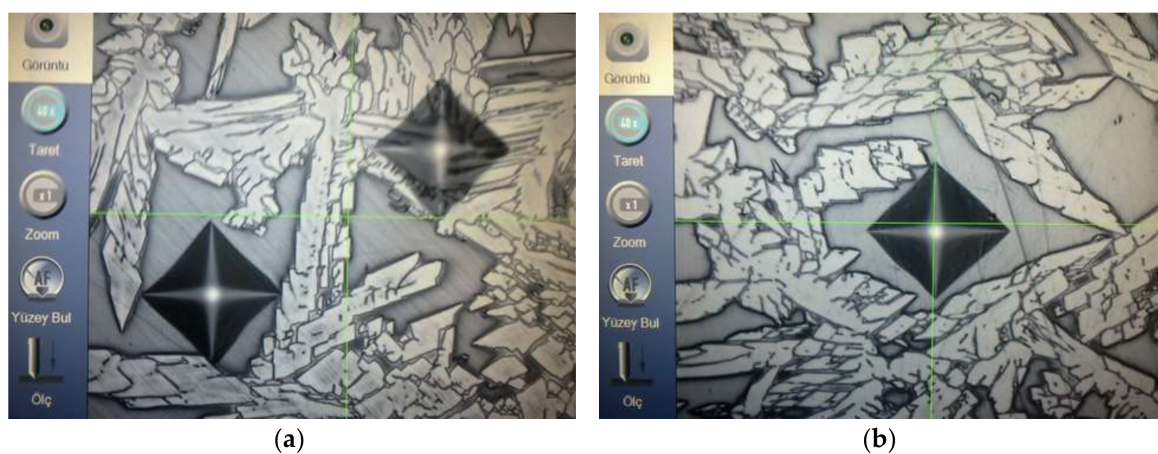


Figure 11. Microvickers hardness testing of (a) δ -ferrite (dark phase), austenite (light-white phase) (b) δ -ferrite on weld metal zones.

The hardness profiles of base metal and weldments are shown in Table 6 below.

Table 6. Hardness profiles of base metal and weldments.

Specimen	Micro-Vickers Hardness Values (HV0,3)								Image Analysis Test Results by Volume % (ASTM E562-ASTM E1245)	
	Austenite				δ -Ferrite				Austenite.	Delta-Ferrite
	Test No. 1	Test No. 2	Standard Deviation	Mean Value	Test No. 1	Test No. 2	Standard Deviation	Mean Value		
Base Metal (unwelded)	305	305	0	305	309	309	0	309	54	46
Pure argon	273	277	2.828	275	261	253	5.657	257	63.3	36.7
1% N ₂ + Argon	332	332	0	332	272	272	0	272	54.2	45.8
3% N ₂ + Argon	278	278	0	278	269	269	0	269	55.6	44.4
6% N ₂ + Argon	281	290	6.364	286	275	275	0	275	36.5	63.5
9% N ₂ + Argon	285	285	0	285	272	272	0	272	33.8	66.2

The micro-hardness values in Table 6 and in Figure 12 point out that, in all tested specimens, the hardness of austenite phase is greater than that of δ -ferrite at the same conditions of welding as a main result of austenite phase, which exhibits a finer microstructure than δ -ferrite in all specimens.

Beginning from the sample that was welded by 1% N₂ added to argon shielding gas, the austenite micro hardness values are greater than that of δ -ferrite in all specimens. However, in base metal, the hardness values of austenite are approximately in close values with δ -ferrite from Table 6. Authors have indicated in their research that raising the nitrogen content preferentially strengthens the austenite by interstitial solid solution hardening rather than δ -ferrite [1,14]. Min Ho Jang et al. declared that “the austenite becomes stronger than the ferrite when nitrogen content partitioned into austenite is higher than 0.5 wt % [14].

The authors have proposed that nitrogen content in argon shielding gas seems to have little significant effect on the hardness of weld metal in TIG welding of UNSS31803 duplex stainless steel within their study [8].

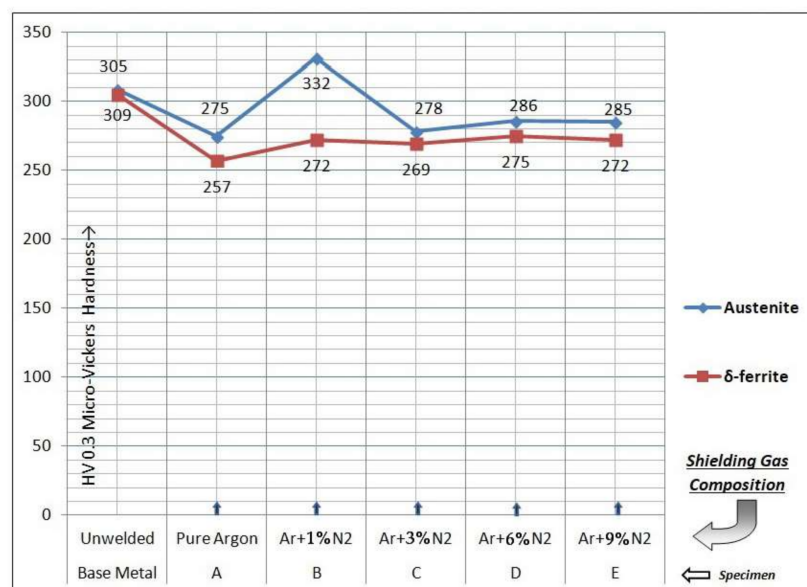


Figure 12. The effects of shielding gas composition on micro-hardness values of base metal and weldments.

4. Discussion

As the nitrogen amount in the argon shielding gas increases, the ratio of δ -ferrite decreases. Nitrogen stabilizes the austenitic microstructure [1,2,5,7,26].

Nitrogen gas spheroidizes the microstructure as apparently seen from Figure 2. Increasing nitrogen gas in argon shielding gas makes the austenitic structure become rounder instead of a needle-like structure in the weld metal.

As in this research, the investigators have noted in their studies that the acicular morphology of the austenite phase in the welded duplex stainless steels changes to globular morphologies as nitrogen content increases in the shielding gas [7].

ASTM E112 grain size analysis is applied by Kameram software. The grain size is significantly influenced by composition of welding shielding gases in this research. As all the weldment specimens were joined in the same welding conditions by the TIG welding process, the grain sizes of specimens are influenced by shielding gas compositions.

Increasing nitrogen gas in argon shielding gas makes the ferritic and austenitic microstructure become coarser up to 6 vol % nitrogen gas, as seen from Table 5 and Figure 6.

Raising the nitrogen content preferentially strengthens the austenite by interstitial solid solution hardening (C, N) to the point where it becomes stronger than the ferrite. Besides this mechanism, strengthening due to the grain refinement of phases is also possible, as noted in literature [1].

Effects of nitrogen additions on yield ($R_{p0.2}$) strength and ultimate tensile strength (R_m) of duplex stainless steels investigated by workers pointed out that increasing nitrogen gas also increases the strength of duplex stainless steels by the mechanism of interstitial solid solution hardening [1,2].

In this study, the austenite phases microvickers hardness of pure argon-welded specimen is estimated as 275 HV_{0.3}, while the hardness of austenite phase in 1 vol % nitrogen gas amount addition to argon shielding gas specimen is determined as 332 HV_{0.3}.

When the nitrogen amount is increased up to 3 vol %, microhardness value of austenitic microstructure decreases again to 278 HV_{0.3}. Hence, 1 vol % nitrogen level is the limit for strengthening the mechanism in austenitic phase.

5. Conclusions

Increasing N₂ gas amount in argon shielding gas increased the amount of austenitic structure and decreased the δ -ferrite amount in the fusion and HAZ zones due to the strong stabilizing effect of nitrogen on austenite.

According to test results, the optimum (35–65 vol %) phase balance of austenite and δ -ferrite should be accomplished solely by adding 1 vol % nitrogen gas into argon shielding gas.

Nitrogen gas in argon shielding gas gained spheroidized microstructures instead of a pin-like appearance in weld metal as seen in almost whole microstructures.

Welding shielding gas composition has great importance to both distribution of phases and grain sizes, and furthermore on hardness values.

Besides, nitrogen gas strengthened the austenitic structure to a point by addition of 1 vol % into argon shielding gas. The finer austenitic structure with respect to δ -ferrite caused increase to the strength of the austenite.

1 vol % nitrogen addition into the argon shielding gas maintains not only strength benefits but also results in proper distribution of austenite and δ -ferrite phases in welding of duplex stainless steels, as is desired in base metals.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gunn, N.R. *Duplex Stainless Steels, Microstructures, Properties and Applications*; Abington Publishing: Cambridge, UK, 2003.
2. Lippold, J.; Kotecki, D. *Welding Metallurgy and Weldability of Stainless Steels*; Wiley Interscience Publications: Hoboken, NJ, USA, 2005.
3. Liou, H.-Y.; Pan, Y.-T.; Hsieh, R.-I.; Tsai, W.-T. Effects of Alloying Elements on the Mechanical Properties and Corrosion Behaviors of 2205 Duplex Stainless Steels. *J. Mater. Eng. Perform.* **2001**, *10*, 231–241. [[CrossRef](#)]
4. Iglesias, F.A.C.; Roman, J.M.R.; Prieto, J.M.R.; Cambronero, L.G.; Godino, F.J.I. Effect of nitrogen on sintered duplex stainless steels. *Powder Metall.* **2003**, *46*, 39–42. [[CrossRef](#)]
5. Kou, S. *Welding Metallurgy*, 2nd ed.; Wiley Interscience Publications: Hoboken, NJ, USA, 2002.
6. Sathirachinda, N.; Pettersson, R.; Wessman, S.; Pan, J. Study of nobility of chromium nitrides in isothermally aged duplex stainless steels by using SKPFM and SEM/EDS. *Corros. Sci.* **2010**, *52*, 179–186. [[CrossRef](#)]
7. Muñoz, A.I.; Antón, J.G.; Guinón, J.L.; Herranz, V.P. Effect of Nitrogen in Argon as a Shielding Gas on Tungsten Inert Gas Welds of Duplex Stainless Steels. *Corrosion* **2005**, *61*, 693–705. [[CrossRef](#)]
8. Muthupandi, V.; Srinivasan, P.B.; Seshadri, S.K.; Sundaresan, S. Effect of nitrogen addition on formation of secondary austenite in duplex stainless steel weld metals and resultant properties. *Sci. Technol. Weld. Join.* **2004**, *9*, 47–52. [[CrossRef](#)]
9. Udayakumara, T.; Rajaa, K.; Abhijit, A.T.; Sathiyab, P. Experimental investigation on mechanical and metallurgical properties of super duplex stainless steel joints using friction welding process. *J. Manuf. Process. Elsevier* **2013**, *15*, 558–571. [[CrossRef](#)]
10. Yan, J.; Wang, J.; Lin, Y.; Gu, T.; Zeng, D.; Huang, R.; Ji, X.; Fan, H. Microstructure and Properties of SAE 2205 Stainless Steel After Salt Bath Nitrocarburizing at 450 °C. *J. Mater. Eng. Perform.* **2014**, *23*, 1157–1164. [[CrossRef](#)]
11. Migiakis, K.; Papadimitriou, G.D. Effect of nitrogen and nickel on the microstructure and mechanical properties of plasma welded UNS S32760 super-duplex stainless steels. *J. Mater. Sci.* **2009**, *44*, 6372–6383. [[CrossRef](#)]
12. Poonguzhali, A.; Pujar, M.G.; Mudali, U.K. Effect of Nitrogen and Sensitization on the Microstructure and Pitting Corrosion Behavior of AISI Type 316LN Stainless Steels. *J. Mater. Eng. Perform.* **2013**, *22*, 1170–1178. [[CrossRef](#)]
13. Tseng, C.; Liou, H.; Tsa, W. Effect of Nitrogen Content on the Environmentally-Assisted Cracking Susceptibility of Duplex Stainless Steels. *Metall. Mater. Trans.* **2003**, *34*, 95–103. [[CrossRef](#)]
14. Jang, M.; Moon, J.; Lee, T.H.; Park, S.J.; Nam Han, H. Effect of Nitrogen Partitioning on Yield Strength in Nitrogen-Alloyed Duplex Stainless Steel During Annealing. *Miner. Met. Mater. Soc.* **2014**, *45*, 1653–1658. [[CrossRef](#)]
15. Lothongkum, G.; Wongpanya, P.; Morito, S.; Furuhashi, T.; Maki, T. Effect of nitrogen on corrosion behavior of 28Cr-7Ni duplex and microduplex stainless steels in air-saturated 3.5 wt % NaCl solution. *Corros. Sci.* **2006**, *48*, 137–153.
16. ASTM A923. *Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Stainless Steels*; ASM International: Almere, The Netherlands, 2008.
17. ASM Handbook. *Metallography and Microstructures of Stainless Steels and Maraging Steels*; ASM International: Almere, The Netherlands, 2004.
18. ASTM E562-11. *Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count*; ASM International: Almere, The Netherlands, 2011.
19. ASTM E1245-03. *Standard Practice for Determining the Inclusion or Second Phase Constituent Content of Metals by Automatic Image Analysis*; ASM International: Almere, The Netherlands, 2008.
20. EN ISO 8249. *Welding-Determination of Ferrite Number (FN) in Austenitic and Duplex Ferritic-Austenitic Cr-Ni Stainless Steel Weld Metals*; European Standard: Brussels, Belgium, 2000.
21. EN ISO 17655. *Destructive Tests on Welds in Metallic Materials-Method for Taking Samples for Delta Ferrite Measurement*; European Standard: Brussels, Belgium, 2003.
22. AWS A4.2. *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal*; ASM International: Almere, The Netherlands, 2006.

23. ASTM E112-12. *Standard Test Methods for Determining Average Grain Size*; ASM International: Almere, The Netherlands, 2012.
24. Jimenez, J.A.; Carsi, M.; Ruan, O.A. Characterization of a duplex stainless steel. *J. Mater. Sci.* **2000**, *35*, 907–915. [[CrossRef](#)]
25. Mariappan, R.; Kumaran, S.; Rao, T.S.; Chandrasekar, S.B. Microstructure and mechanical properties of duplex stainless steels sintered in different atmospheres. *Powder Metall.* **2011**, *54*, 236–241. [[CrossRef](#)]
26. ASM Metals Handbook. *Welding Brazing and Soldering*; ASM International: Almere, The Netherlands, 1993.



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