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Analysis of mechanical and microstructural characteristics of AISI 430 stainless steel welded by GMAW

İsmail Açar[1], Bekir Çevik[2]*, Behçet Gülenç[3]

[1] *Institute of Science and Technology, Gazi University, 06500 Ankara, Turkey*
[2] *Department of Biosystems Engineering, Düzce University, 81620 Düzce, Turkey*
[3] *Department of Metallurgical and Materials Engineering, Faculty of Technology, Gazi University, 06500 Ankara, Turkey*

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Abstract

The use of stainless steels in the machine manufacturing industry is increasing day by day. Due to the poor corrosion properties of especially unalloyed and low-alloy steels, stainless steels are among the preferred materials in industrial applications because of their superiorities such as high corrosion resistance, very good forming and welding capabilities, hygiene and aesthetic appearance. The welding requirements of stainless steels with such widespread use potential are inevitable. For this reason, studies on welding joining stainless steels are important. In this study, AISI 430 ferritic stainless steel materials were joined using different shielding gas combinations through the gas metal arc welding (GMAW) method. In the welding operations, pure argon (100 % Ar), 97 % Ar + 3 % H_2, and 93 % Ar + 7% H_2 gas combinations were used. The effect of shielding gas combined with the mechanical and metallographic tests applied to the welded sheets on the mechanical and microstructural properties of AISI 430 stainless steel was investigated. In the results obtained from the study, a noticeable grain coarsening occurred in the microstructure of the weld metal and HAZs with the addition of H_2 to the Ar gas during the welding process. The highest tensile strength was obtained from the joints welded with 97 % Ar+3 % H_2 mixture gas. As a result of the tensile test, a rupture occurred in the base metal in all welded samples. No crack or tear defect was found in the weld zone due to the bending test.

Key words: GMAW, AISI 430 stainless steel, gas combination, mechanical properties, microstructure

1. Introduction

Ferritic stainless steels, important in the stainless steel family, are iron-chromium (Fe-Cr) alloys containing approximately 11–30 % chromium and up to 0.05–0.2 % carbon [1, 2]. In addition, these steels contain alloy elements such as 0.01–0.25 % carbon, up to 0.3–2.5 % manganese, up to 0.2–1 % silicon, up to 0.75–2.5 % molybdenum, and small amounts of titanium, niobium, copper, sulfur, phosphorus, and aluminum [3, 4]. Ferritic stainless steels have a ferrite structure at all temperatures due to ferrite forming alloying elements [5]. Therefore, the current dominant metallurgical phase in these steels is ferrite. In other words, these steels do not form austenite, so it is not possible to harden them by heat treatments. Ferritic stainless steels exhibit good corrosion resistance, depending on the increase in the chromium content they contain [5, 6]. Their formability and welding capabilities are low compared to austenitic stainless steels [7]. Nevertheless, they are used in many industrial applications because of their high corrosion resistance. The use of ferritic stainless steels in environments containing particularly caustic and chlorides is suitable. Therefore, they are preferred in industrial applications such as chemical processing equipment, oil refining equipment, storage vessels, furnace parts and heat exchangers, electrical devices, and solar water heaters [5–8].

The welding process is an important manufacturing technology that is still popular for joining metals and providing high-quality joints in industrial applications [3, 9]. As a result of the rapid increase in the

*Corresponding author: bekircevik@duzce.edu.tr

use of stainless steels in industrial applications, the welded joints of such steels have become very important [3, 6, 8]. Many types of stainless steels can be joined by various fusion welding methods. Gas metal arc welding (GMAW) and gas tungsten arc welding (GTAW) are among the top welding methods used for stainless steels. GMAW and GTAW methods are preferred more than other welding methods since they provide many advantages [6, 7]. However, some metallurgical transformations/events during the welding process of ferritic stainless steels make fusion welding of these alloys difficult. In particular, the fusion welding of AISI 430, AISI 442, and AISI 446 type ferritic stainless steels is associated with many problems, such as grain growth in both the fusion zone and HAZ and the formation of martensite at the grain boundary in the weld zone. This may negatively affect the ductility and toughness of the weld [6, 10].

GMAW method is the most commonly used fusion welding method in welding steels and non-ferrous metals in the industry [11]. In this method, massive welding wires are used. The heat required for welding is generated through the arc forming between a workpiece and a melting and continuously fed wire electrode and by heating the resistance forming on the electrode by the welding current passing through the electrode. The welding wire is automatically sent to the arc zone, melts, and forms the weld metal [12–14]. With the GMAW method, the weld zone is protected by inert gas in the welding of stainless steels. In the GMAW method, the shielding gas and/or gas mixtures are selected according to the type of welded metals. The primary function of the shielding gases in the welding process is to protect the molten weld metal from the negative effects of nitrogen and oxygen in the atmosphere [14, 15]. The type and composition of the selected gas significantly affect the microstructure and mechanical properties of the joined material [6, 13, 15]. Also, shielding gas or gases affect the heat input, metal transfer type, and the characteristics of the arc formed [2, 3, 6, 16]. Argon (Ar) and helium (He) gases are used alone or as a mixture in welding some types of stainless steels with the GMAW method; however, when some studies in the literature are examined, it is seen that different gases such as oxygen (O_2) and hydrogen (H_2) at different ratios are added to these gases in recent times [11–16]. Studies on the shielding gas selection in welding of stainless steels and the effect of shielding gas on the mechanical and metallurgical properties of the weld zone continue intensively. Sathiya et al. [17] welded super austenitic stainless steel sheets by CO_2 laser-GMAW hybrid welding process using different gas combinations. They stated that the shielding gas combination is effective in the form of the welding seam as well as tensile, hardness, and toughness properties. They reported better mechanical properties with 50 % He + 45 % Ar + 5% O_2 gas mixture. Liao and Chen [18] welded AISI 304 stainless steel sheets with gas metal arc welding and flux-cored arc welding methods using different gas combinations. They reported the best mechanical properties when using 98 % Ar + 2 % CO_2 gas. Karthi et al. [19] welded martensitic stainless steel and carbon steel materials using tungsten inert gas (TIG) welding with various shielding gas and filler combinations and investigated the mechanical and microstructural properties of the welded joints. They reported the best mechanical properties in the joint welded by using duplex stainless filler wire in argon shielding gas protection. Açar and Gülenç [20] investigated the effect of different shielding gas combinations on mechanical and microstructural properties of 316 austenitic stainless steel joined by using the Metal Inert Gas (MIG) welding method. They reported that the best mechanical properties were obtained from the joints welded in a pure argon gas atmosphere. Shielding gases are important in protecting molten metal from atmospheric contamination during welding. These gases play an important role in determining the mechanical and metallurgical properties of weld seams, including arc properties and microstructure of weld seams [17–19]. Therefore, it is important to understand the effect of welding shielding gases on different materials since both steels and non-ferrous metals and alloys are welded with the GMAW method, and more extensive studies are still being carried out by many researchers [13, 20]. In addition, environmental effects are among the most important issues in the production of new generation technologies [1, 3, 6, 13]. Nowadays, where raw material resources are constantly consumed, the interest in longer-lasting materials increases every day. Because of their superior properties and longer life under corrosive conditions, stainless steels have gained more importance for engineers and designers, and the use of these steels is increasing day by day. For this reason, further studies are needed on the welding of stainless steels [2–8,16–20].

This study investigated the effect of different shielding gas combinations on the mechanical and microstructural properties of AISI 430 ferritic stainless steel welded with GMAW. To determine the effect of shielding gas type on the mechanical properties of the welded joints, tensile, bending, and hardness tests were applied. In addition, macrostructures and microstructures occurring in the weld metal and the heat-affected zone (HAZ) were evaluated.

2. Experimental

2.1. Material

In this study, AISI 430 ferritic stainless steels with the dimensions of 250 × 125 × 2 mm^3 were welded

Table 1. Chemical composition of base material and welding wire (wt.%)

	C	Mn	Si	Cr	Ni	P	S
AISI 430 stainless steel	0.08	2.0	1.0	16–18	10–14	0.045	0.03
Welding wire	0.03	1.70	0.85	18.5	12.5	0.045	0.03

Table 2. Mechanical properties of base material and welding wire

	Yield strength (MPa)	Tensile strength (MPa)	Elongation %
AISI 430 stainless steel	259.8± 2	416.2± 2	46.2± 2
Welding wire	410	640	40

Table 3. Welding parameters

Welding current	80 A ± 2		
Welding voltage	20 V ± 2		
Wire speed	3.5 m min^{-1}		
Welding speed	5 mm s^{-1}		
Gas flow rate	10 lt min^{-1}		
Electrode diameter	1 mm		
Shielding gas	Ar 100 %	97 % Ar + 3 % H_2	93 % Ar + 7 % H_2
Welding code	GMAW-1	GMAW-2	GMAW-3

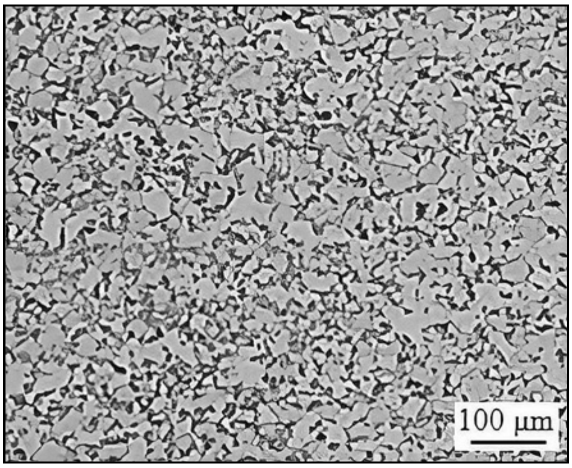

Fig. 1. Microstructure of AISI 430 ferritic stainless steel.

by GMAW. 316L quality wire (EN 12072) with a 1-mm diameter was used as welding wire in the welding operations. Table 1 shows the chemical compositions of AISI 430 ferritic stainless steel and welding wire, Table 2 shows their mechanical properties, and Fig. 1 shows the microstructure image.

2.2. Welding process

During GMAW, all welding parameters were kept constant, and the chemical composition of the shielding gas (100 % Ar, 97 % Ar + 3 % H_2, and 93 % Ar + 7 % H_2) was changed. In the welding processes, Buğra™ 550SW gas metal arc welding machine was used. Before welding, AISI 430 ferritic stainless steel sheets were fixed face-to-face without any gap, and the welding operations were performed in the horizontal position using the welding parameters in Table 3. The welding parameter values used in the studies were decided from the preliminary studies. After the welding operations, the samples were left to cool down in the open air.

2.3. Testing procedures

Macrostructure and microstructure examination, as well as hardness, tensile, bending and fatigue tests, were conducted on AISI 430 ferritic stainless steel sheets joined by GMAW. 3 tensile samples, 3 bending samples, 1 microstructure and hardness sample were prepared from the welded samples. Tensile test samples were prepared according to the ASTM-E8 standard. Bending test samples were manufactured according to TS EN ISO 5173 standard. The schematic picture of the tensile and bending test specimens is given in Fig. 2. Tensile tests were performed using a 100 kN Besmak™ BME-T series universal tensile test device. Three-point bending tests were performed using a 50 kN Instron™ 3369 tensile/bending test de-

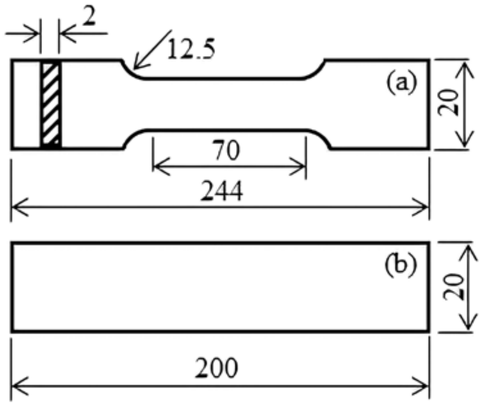

Fig. 2. The schematic picture of the tensile and bending test specimens.

vice at 10 mm min^{-1} test speed and a support span of 100 mm. The diameter of the support parts of the three-point bending tester is 20 mm. Sandpapering, polishing, and etching processes were applied to the microstructure and hardness samples with standard methods. The samples were etched with 10 % oxalic acid ($C_2H_2O_4$) and 90 % distilled water mixture solution, and the examinations were performed using a Leica™ DFC450 metal microscope. The hardness distribution of the welded samples was determined using Qness™ Q30 M trademark Vickers ($HV_{0.5}$) hardness test device.

3. Results and discussion

3.1. Microstructure

Figures 3–5 show weld zone microstructures of the AISI 430 ferritic stainless steel joints welded by GMAW in different gas combinations. The microstructure images of the welded joints were taken from the weld center and the transition zones. Due to the arc forming between the AISI 430 ferritic stainless steel sheets fixed face-to-face with welding wire during GMAW, both the welding wire melted and the stainless steel sheets locally melted and solidified to form the weld metal [17, 20]. As a result of the visual inspection made on the welded sheets, no macro welding defects such as pores, macro cracks, burning grooves, etc., on the upper and lower surfaces of the weld seams were determined. When 100 % Ar shielding gas atmosphere was used during the welding process, an easy arc ignition was achieved, a stable arc was formed, and a spatter-free weld seam was obtained. It was determined that H_2 gas added into argon gas at 3 and 5 % rates increased the weld seam width during the welding process. It was also seen that there was no angular distortion in the welded sheets in the transverse or longitudinal direction.

Due to the high heat input applied locally during GMAW, microstructural properties previously gained by the stainless steel materials transformed in the melting zone and near the melting zone. When the microstructure images were examined, it was seen that the shielding gas combination also affected this transformation in the weld zone. Therefore, the microstructure of the weld metal was different from the mi-

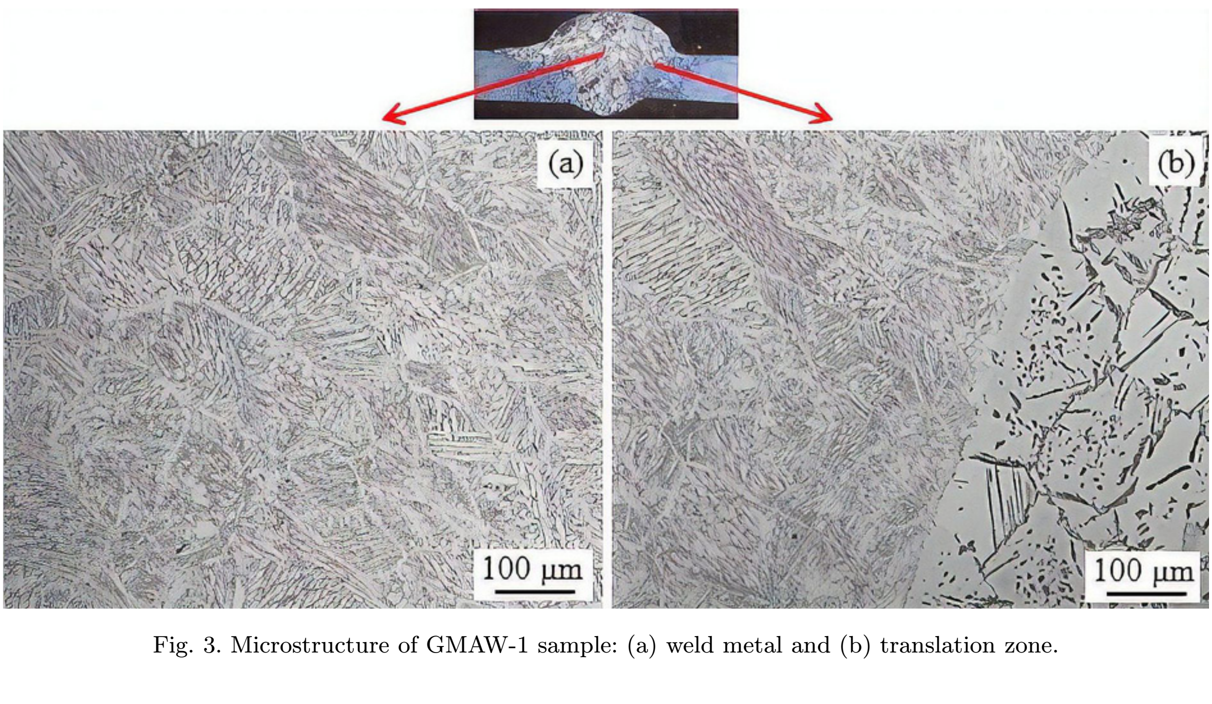

Fig. 3. Microstructure of GMAW-1 sample: (a) weld metal and (b) translation zone.

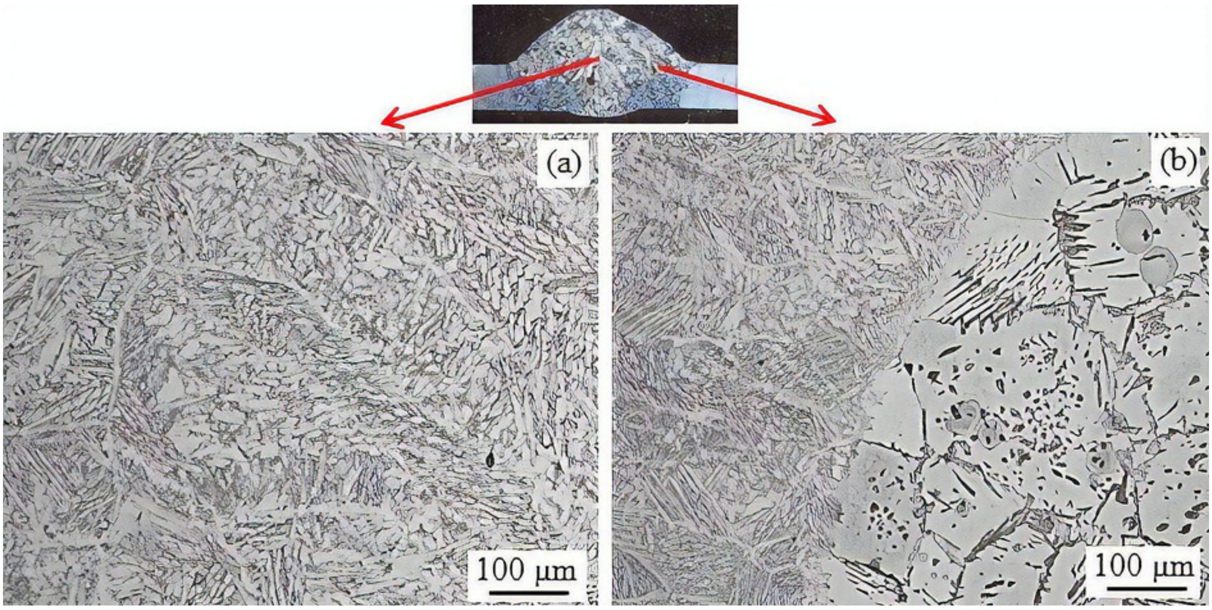

Fig. 4. Microstructure of GMAW-2 sample: (a) weld metal and (b) translation zone.

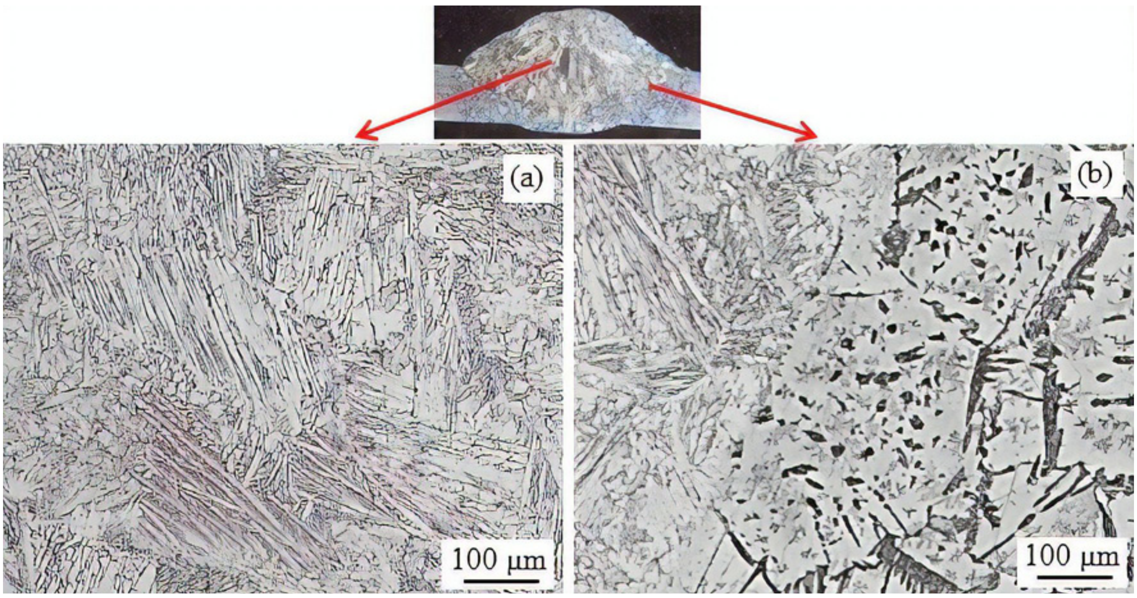

Fig. 5. Microstructure of GMAW-3 sample: (a) weld metal and (b) translation zone.

crostructure of AISI 430 ferritic stainless steel. The weld metal of the joint welded by GMAW under 100 % Ar shielding gas atmosphere was determined to have a fine columnar and dendritic grain structure. The low heat input caused by the Ar gas atmosphere did not allow the weld metal microparticles to become coarse. In addition, it can be seen that the weld metal particles in the transition zone of the weld seam are formed by directing toward the weld center. Upon the addition of H_2 to Ar gas during GMAW, an apparent grain size coarsening was caused in the microstructure of weld metal. Depending on the addition of 3 % H_2 to argon gas, the microstructure of the weld center changed, and coarser columnar and dendritic grains formed. It was determined that grain boundary ferrite, Widmanstätten ferrite, fine polygonal ferrite, and martensite grains formed in the microstructures of both GMAW-1 and GMAW-2 welded samples. 5 % H_2 gas added to the argon gas increased the heat input and melting power and caused the weld metal grain size of the GMAW-3 sample to grow even more compared to the weld metals of both GMAW-1 and GMAW-2 samples. Coarser grain boundary ferrite, Widmanstätten ferrite, polygonal ferrite, and martensite grains formed in the weld metal of the GMAW-3 sample. Katherasan et al. [21]

T a b l e 4. Hardness ($HV_{0.5}$) test distributions of welded samples

	Measuring point	GMAW-1		GMAW-2		GMAW-3	
		Hardness	Average	Hardness	Average	Hardness	Average
Base metal	–8 –7 –6	158 161 151	156.6	156 155 161	157.3	156 167 152	158.3
HAZ	–5 –4 –3 –2	216 261 237 249	240.7	187 247 247 256	234.2	173 189 247 240	212.2
Welding metal	–1 0 1	213 243 241	232.3	224 239 226	229.6	244 272 248	254.6
HAZ	2 3 4 5	237 185 261 174	214.2	247 244 256 226	243.2	243 224 195 176	209.5
Base metal	6 7 8	167 155 152	158	175 157 151	161	157 151 150	152.6

expressed that type and composition of shielding gas were significantly effective on the weld microstructure of AISI 316L austenitic stainless steel sheets joined by FCAW and different gas combinations. When the microstructures of the transition zones of the welded joints were examined, it was determined that micro-grains formed with different characteristics than both microstructure of AISI 430 ferritic stainless steel and the microstructure of the weld metal. It was found that there was no melting in the transition zone of the welded joints, but micro-grains of the heat-affected zones (HAZ) that were exposed to high heat formed in a coarser size compared to both the micro grains of the base metal and the micro grains of the weld metal. In addition, when HAZ microparticles of the welded samples were compared, it was determined that more coarse grains formed in parallel with the increase in H_2 ratio added to argon gas. Çevik [16] reported that shielding gas composition directly affected the heat input and caused the weld metal and HAZ micro grains to be coarse. The physical and chemical properties of argon and hydrogen gases were different. As a result of the combination of the properties of both gases, very important properties can be gained by the weld seams of AISI 430 ferritic stainless steels [20].

3.2. Hardness

Table 4 and Fig. 6 show hardness distributions of the weld zone of the AISI 430 ferritic stainless steel joints welded by GMAW in different gas combinations. As a result of the hardness test, the hardness of the

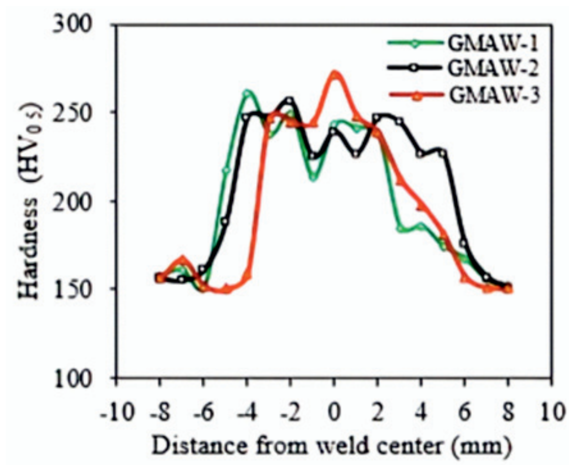

Fig. 6. Hardness distribution of the welded sample.

weld zone (weld center and HAZs) was determined to be higher than the hardness of AISI 430 stainless steel. The hardness values increased from the base metal toward the weld metal on both sides. The average of three hardness values taken from the weld center was determined as 232.3 $HV_{0.5}$ in the GMAW-1 sample joined with 100 % Ar gas, 229.6 $HV_{0.5}$ in the GMAW-2 sample joined with 97 % Ar+3 % H_2 mixture gas and 254.6 $HV_{0.5}$ in GMAW-3 sample joined with 93 % Ar+7 % H_2 mixture gas. HAZ hardnesses were measured on the left side of the weld (LS) and the right side (RS) of the weld. Hardness measurement average taken from the HAZs of the welded joints was mea-

Table 5. Tensile and three-point bending test results of welded samples

Tensile test results			
	GMAW-1	GMAW-2	GMAW-3
Average yield strength (MPa)	268.9 ± 1	277.1 ± 3	266.7 ± 1
Average tensile strength (MPa)	420 ± 2	427.4 ± 6	415.1 ± 1
Average elongation %	22 ± 1	17.3 ± 6	25.4 ± 1
Three-point bending test results			
	GMAW-1	GMAW-2	GMAW-3
Average bending strength (MPa)	804.9 ± 10	826.6 ± 10	824.2 ± 4

sured as 240.7 $HV_{0.5}$ (LS) and 214.2 $HV_{0.5}$ (RS) in the GMAW-1 sample, 234.2 $HV_{0.5}$ (LS) and 243.2 $HV_{0.5}$ (RS) in GMAW-2 sample, and also 212.2 $HV_{0.5}$ (LS) and 209.5 $HV_{0.5}$ (RS) in GMAW-3 sample. The hardness value of AISI 430 stainless steel was ~ 155 $HV_{0.5}$. These results determined that the hardness values of the weld center of GMAW-1 and GMAW-2 samples were close to each other, and the 3 % H_2 gas added to argon gas did not significantly affect the weld center hardness of these samples. When 7 % H_2 was added to argon gas, the hardness of the GMAW-3 sample increased slightly. Studies conducted on the effect of shielding gas combinations used in the welding of stainless steels on the weld zone properties have figured out that some added gases increase the hardness of the weld zone and some added gases reduce the hardness values of the weld zone. The martensitic phase forming in the weld zone affected the increase in hardness. Filho et al. [22] reported that the chemical composition of shielding gas affected the hardness distribution of the weld zone of ferritic stainless steel welded using GMAW with pure argon and gas combinations at different ratios (Ar + O_2 and Ar + CO_2). Anand et al. [23] expressed that the shielding gas combinations they used affected the hardness distribution of the weld zone of AISI 304 L austenitic stainless steel welded using the GMAW method with pure argon (100 % Ar) and gas combinations at different ratios (80 % Ar + 20 % CO_2, 50 % Ar + 50 % CO_2, and 100 % CO_2) and the lowest hardness values were determined in the joint welded with 100 % CO_2 shielding gas. The grain coarsening in the HAZs of the welded samples can affect the hardness distribution of the welded joint due to melting, especially in the regions close to the weld metal [16–20]. In addition, the hardness values obtained with the deformation during the production of sheets by rolling may decrease in HAZs, particularly due to the heat input [18–23]. Therefore, it was believed that many factors other than the gas combination used affected the hardness of the weld zone.

3.3. Tensile test results

Table 5 and Fig. 7 show tensile test results of the AISI 430 ferritic stainless steel joints welded by GMAW using different gas combinations. When the tensile test results were examined, the highest tensile strength and % elongation were observed in the base metal. As a result of the tensile test, it was determined that the yield strength of AISI 430 ferritic stainless steel was 259.8 ± 2 MPa, its tensile strength was 416.2 ± 2 MPa, and % elongation was 46.2 ± 2%. In the GMAW-1 sample, the yield strength was 268.9 ± 1 MPa, the tensile strength was 420 ± 2 MPa, and the % elongation was 22 ± 1%. Compared to the tensile test results of the GMAW-1 sample, an increase of 3.5 % and 1 % occurred in the yield and tensile strength; however, there was a decrease of 52.3 % in the % elongation. In the GMAW-2 sample, the yield strength was 277.1 ± 3 MPa, the tensile strength was 427.4 ± 6 MPa, and the % elongation was 17.3 ± 6 %. Compared to the tensile test results of the GMAW-2 sample, there were decreases of 6.6 and 2.6 % in the yield and tensile strength, respectively, but a decrease of 62.5 % occurred in the % elongation. In the GMAW-3 sample, the yield strength was 266.7 ± 1 MPa, tensile strength was 415.1 ± 1 MPa, and the % elongation was 25.4 ± 1%. Compared to the tensile test results of the GMAW-3 sample, there was an increase of 2.6 % in the yield strength, but there were decreases of 0.3 and 62.5 % in the tensile strength and % elongation, respectively. It can be said that the martensitic phase in the weld zone increased the hardness of the weld zone, and accordingly, the yield and tensile strength of the welded samples increased. The tensile test results showed that upon the mixture of Ar and H_2 gases with different physical and chemical properties at specific ratios, very important properties can be given to the weld seams of this combination. Çevik [16], Kılınçer, and Kahraman [24] stated that the first condition for the welding process is the strength of the joint being the same as or

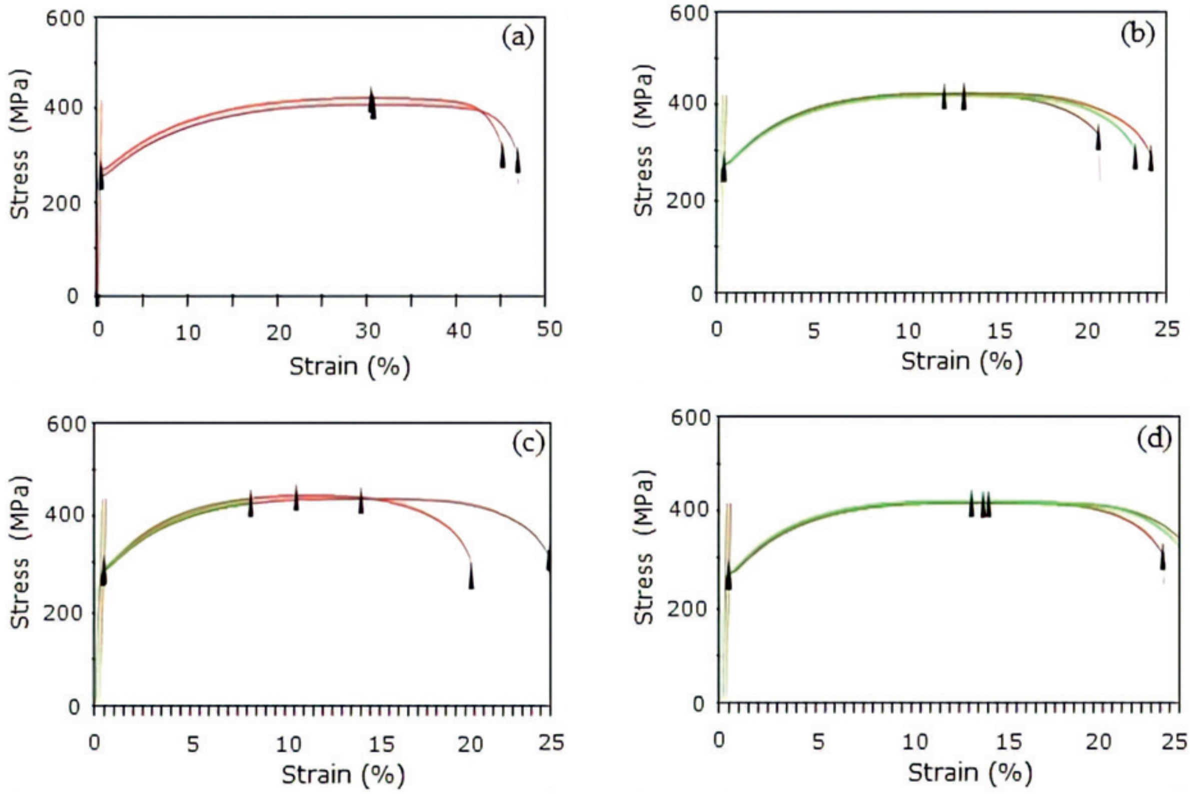

Fig. 7. Tensile test results: (a) base metal, (b) GMAW-1, (c) GMAW-2, and (d) GMAW-3.

close to the base material. When the tensile test results were examined, it can be asserted that all welded samples fulfilled this requirement. However, when the tensile test results of the welded joints were compared, the highest tensile strength was obtained from the GMAW-2 samples welded with 97 % Ar + 3 % H_2 mixture gas. Therefore, it can be asserted that the hydrogen gas added to argon gas positively affected the yield and tensile strength in the welding of AISI 430 ferritic stainless steels at a specific ratio. Bermejo et al. [25] reported that shielding gas combination affected the mechanical properties of duplex and super duplex stainless steels welded with the GMAW method using different gas combinations (pure Ar, Ar + 2 % CO_2, Ar + 30 % He + 2 % CO_2, Ar + 30 % He + 0.5 % CO_2, and Ar + 30 % He + 0.5 % CO_2+ 1.8 % N_2) and higher mechanical properties were obtained when Ar + 30 % He + 0.5 % CO_2 gas mixture was used compared to the joints welded with other gas combinations. When the fracture behaviors of the welded samples were examined, all the samples were determined to rupture from the base metal. Figure 8 shows the fracture behavior of the samples.

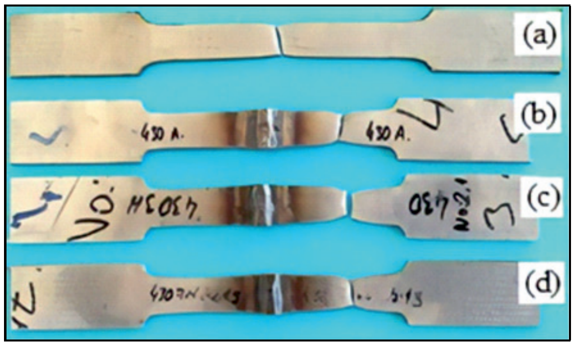

Fig. 8. Fracture behavior of the samples: (a) base metal, (b) GMAW-1, (c) GMAW-2, and (d) GMAW-3.

3.4. Three-point bending test results

To see the behaviors of AISI 430 ferritic stainless steel samples welded by GMAW in different gas combinations against the bending stress, bending tests were applied to the joints from the upper surface (upper surface bending). This test was conducted to evaluate the ductility of butt welded joints on or near their surface and/or if there are defects on the joint surface. Table 5 shows the three-point bending test results of the AISI 430 ferritic stainless steel joints welded by GMAW using different gas combinations. The average of three maximum bending test strength values taken from the welded samples was determined as 804.9 ± 10 MPa in the GMAW-1 sample joined with 100 % Ar gas, 826.6 ± 10 MPa in GMAW-2 sam-

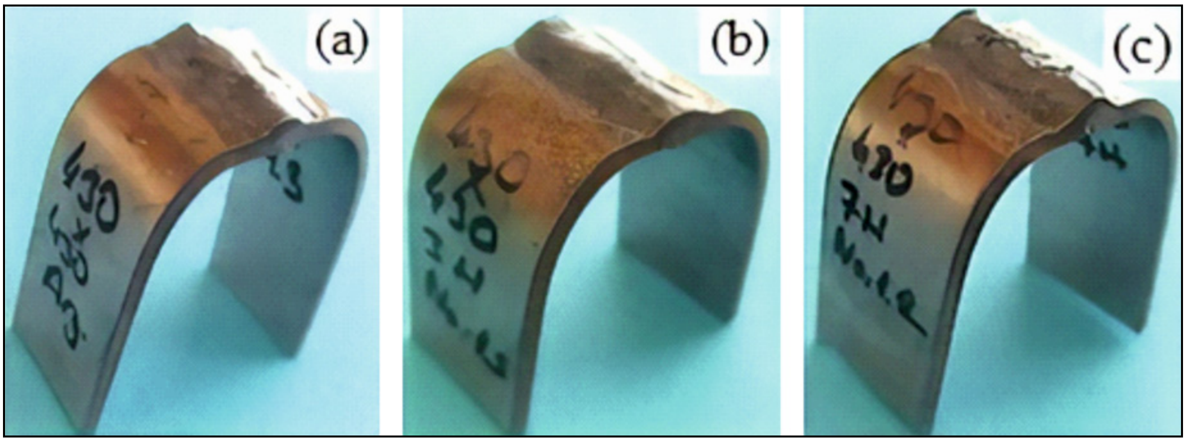

Fig. 9. Bending test behavior of the welded samples: (a) GMAW-1, (b) GMAW-2, and (c) GMAW-3.

ple joined with 97 % Ar + 3 % H_2 mixture gas, and 824.2 ± 4 MPa in GMAW-3 sample joined with 93 % Ar + 7 % H_2 mixture gas. According to these results, it was seen that the maximum bending strength of the GMAW-1 sample was lower than that of the GMAW-2 and GMAW-3 samples. The highest bending strength was determined in the GMAW-2 sample. It was determined that 7 % H_2 gas added to argon gas did not significantly affect the bending strength of the samples compared to the GMAW-2 sample and even slightly decreased it. Figure 9 shows bending behavior images of the samples joined by GMAW. As a result of the bending tests, AISI 430 ferritic stainless steel material was able to bend at 180° without any problem. When the upper surface bending images of AISI 430 ferritic stainless steel joints welded by GMAW in different gas combinations were examined, no cracking or fracture occurred in all welding parameters during the 180° bending test. The absence of any macro weld defect such as pore, macro crack, burning groove, etc., caused the welded samples to be deformed without damage during the bend test. Bending test results showed that by mixing Ar and H_2 gases having different physical and chemical properties at specific ratios in GMAW processes of AISI 430 ferritic stainless steels, very important properties could be given to the bending strength of the weld seams of this combination. Therefore, welded AISI 430 ferritic stainless steel materials joined with three different gas combinations can be used safely by bending at any desired angle up to 180° according to the post-welding service conditions.

4. Conclusions

AISI 430 ferritic stainless steel sheets were joined by GMAW in different gas combinations, and microstructural and mechanical properties of the welded joints were examined, and the obtained results are summarized below:

1. AISI 430 ferritic stainless steel sheets were successfully welded with the GMAW method under 100 % Ar, 97 % Ar + 3 % H_2, and 93 % Ar + 7 % H_2 shielding gas atmospheres.
2. By adding H_2 to Ar gas in GMAW, the grain size of the weld metal and HAZs increased.
3. In the joint welded with 93 % Ar + 7 % H_2 mixture gas, coarser grains formed in both the weld metal and the HAZ.
4. In GMAW processes made with the addition of H_2 to Ar gas, the hardness of the weld metal of AISI 430 ferritic stainless steel sheets was higher than the HAZ and base metal.
5. As a result of the tensile test, the highest strength in the welded joints was obtained from the samples welded with 97 % Ar + 3 % H_2 shielding gas mixture. As a result of the tensile tests, the rupture occurred in the base metal in all welded joints.
6. As a result of the bending test, the highest bending strength was obtained from the samples welded with 97 % Ar + 3 % H_2 shielding gas mixture.

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