Effects of Shielding Gas on the Depth, Width and Hardness of 17-4PH Stainless Steel during TIG Welding

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Abstract

The present study investigates the effects of type of shielding gas on the depth, width and hardness of 17-4PH stainless steel. For this purpose, pure He, pure Ar and 80%Ar + 20% He were used as shielding gases in TIG welding of 17-4PH SS. Weld depth and width of specimens were measured by macro etching. Microstructure of welds was studied by using SEM technique. Moreover, micro Vickers hardness test was accomplished to gauge the hardness of welds. Results showed that specimen welded with pure He has the highest hardness values in the weld zone due to the reduction of δ-ferrite formation in the martensitic matrix. Furthermore, owing to the lower thermal conductivity and heat input of Ar gas, specimen welded by pure Ar has the shallowest and narrowest weld bead. However, due to produce hotter arc by addition of He in shielding gas, enhancements observed in the weld depth and width of specimens welded with pure He and 80%Ar + 20% He.

Keywords: 17-4PH Stainless Steel, TIG Welding, Hardness, Microstructure, Penetration.

1. Introduction

Stainless steels can be divided into five groups where each group involves various grades with defined standard composition ranges. The first four groups are ferritic, austenitic, duplex (ferritic-austenitic) and martensitic stainless steels characterizing with their crystallographic microstructure. The fifth group, precipitation hardening (PH), is characterized with their capability to be heat treated [1]. This Variation occurs because of the differences in their chemical composition and behavior during heat treatment. The corrosion resistance is a result of a very thin chromium oxide layer on the surface of stainless steels [2-3]. Despite the combination of high strength and corrosion resistance, the PH stainless steels are not as widely used as the other grades. Many of the martensitic and semi-austenitic alloys are used in demanding aerospace and defense applications such as high-pressure gas bottles to be use to actuate wings, rudders and other guidance systems on self-guided missiles are built from PH stainless steel. The missile launch tubes on nuclear submarines are also constructed from PH alloys (usually 17-4PH). The combination of high specific strength and corrosion resistance meet the needs of these applications [4]. Addition of Nb to PH stainless steel is produced17-4PH (UNS S17400) alloy, Type 630, which is a chromium-nickel-copper precipitation-hardening martensitic stainless steel with high strength and hardness and good corrosion resistance. It should not be used at temperatures above 572°F (300°C) or for cryogenic service.

The corrosion resistance of Alloy 17-4PH is comparable to 304 stainless steel in most environments, and is generally superior to the 400 series stainless steels. The application of this alloy is where the combination of moderate corrosion resistance and unusually high strength are required [5].

The microstructure of the 17-4PH SS[1] in as welded condition consists of interdendritic delta ferrite in the martensitic matrix [6]. 17-4PH SS[1] has strengthened due to small precipitates of Cr and Nb carbides and nano-Cu precipitates [7].

The weldability of 17-4 PH martensitic SS is good for the traditional arc welding processes such as gas tungsten arc welding (GTAW) and shielded metal arc welding (SMAW) [8]. TIG welding process commonly is performed by using 2% thoriated tungsten (Th-2), DC straight polarity (DCEN) and ER630 as a filler metal [9].

Argon or helium or mixtures of the two gases are used to protect the end of the electrode, arc, and the molten weld puddle from the atmosphere during welding. Argon is used for manual GTA welding of precipitation-hardening stainless steel for several reasons. The argon-arc is smooth and easy to start and control. In compare with helium, the argon-arc is cooler which means that the weld puddle will be smaller and the welding operator will have better control over penetration.

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[1] SS: Stainless steel

Argon is more use than helium because it's cheaper and it has lower flow rate. Whereas, the higher heat rate of helium-shielded arc is caused to be used in high travel speed processes. The travel speed can be increased as much as 40%by using helium instead of argon. In this way, heavier passes can be made and the joint can be completed quicker. The obtained arc from using mixture of helium and argon has less penetrating than the arc obtained with pure helium [10]. So, a mixture of argon and helium is used when the hotter arc and higher penetration are required. Penetration will be increased by increasing of helium percentage [11]. Bitharas et al. [12] investigated the visualization of alternating shielding gas flow in TIG welding. The result of this study is shown in Fig. 1. It is obvious that using pure helium for welding will produce a considerably larger weld size and more penetration than argon Liu et al. [13] welded 17-4PH SS plates with a thickness of 19mm. They reported that ferrite and martensite were observed in the weld zone. Also, Hosseini Hosseinabad [14] studied TIG welding of 17-4PH SS by using ER630 filler metal. He reported that $\delta - ferrite$ exists in the martensitic matrix of weld. Sufizadeh et al. [16] used pulsed Nd:YAG laser to welding 17-4PH SS and studied the effect of welding parameters on geometry and microstructure of weld.They illustrated the presence of δ-ferrite in the microstructure of 17-4PH SS welds. Furthermore, they stated that the reduction of the weld hardness is related to the presence of δ-ferrite. In this study, TIG welding was used to welding 17-4PH SS plates with a thickness of 4mm and no filler metal used. In order to achieve the full penetration, the effect of shielding gases on weld depth and width were investigated. Moreover, microstructural evaluation of 17-4PH welds was performed to find the effects of shielding gases on the welds microstructure and hardness.

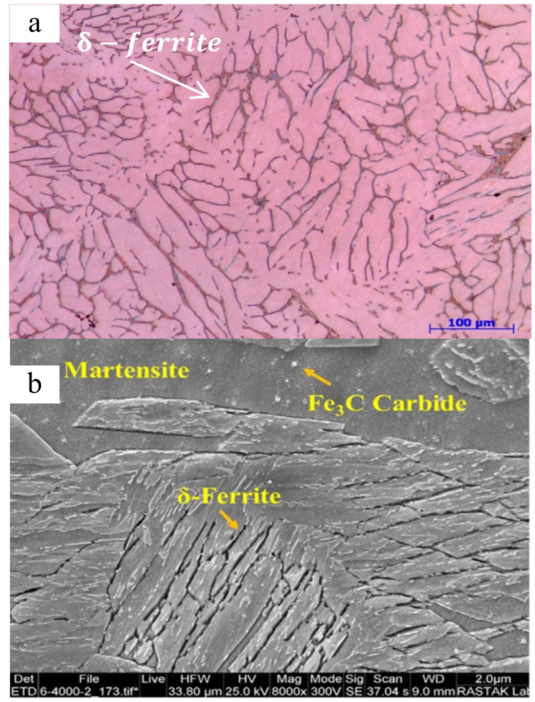

Fig. 2. a) Optical micrograph, b) SEM micrograph of welded 17-4PH SS [15].

2. Materials and Methods

Chemical composition of 17-4PH plates with a thickness of 4mm which used in this research was determined by Spectro OES device. Table. 1. shows its chemical composition.

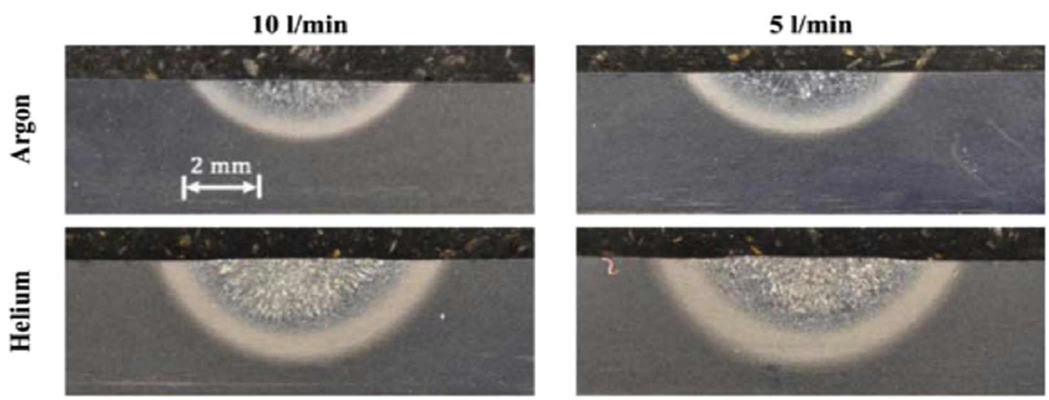

Fig. 1. Weld macrographs showing effect of shielding gas configuration on TIG welding [12].

Table. 1. Chemical composition of 17-4PH SS(wt.%).

C	Si	Mn	P	S	Cr	Ni	Mo
0.023	0.243	0.313	0.024	0.014	15.970	5.070	0.312
Fe	**Al**	**Cu**	**Co**	**Ti**	**Nb**	**V**	**W**
73.800	0.007	3.580	0.055	0.003	0.271	0.079	0.182

DIGTIG 401 AC/DC welding machine was used for welding 17-4PH SS specimens. Automatic TIG welding was performed by using PEG1 Tractor welding robot which is made by Kara Co. Welding robot is shown in (Fig. 3.).

Fig. 3. PEG1 Tractor welding robot.

Ar and He gas cylinder with purity of 99/99% was supplied separately. MixMaster gas mixer device was used to mixing gases with the desired ratio. Bead on plate welding was performed on specimens. Welding parameters is shown in (Table. 2.).

Table. 2. Parameters specifications used for welding.

Electrode Diameter(mm)	Speed (mm/s)	Debi (Lit/min)	Gas(%)	Current (A)
3.2	2.15	8	100 Ar	130
3.2	2.15	8	100 He	130
3.2	2.15	8	20 He +80Ar	130

Micro Vickers hardness test was done on specimens by force of 100g at 10s.

After preparing the metalographic specimens the polishing was done by Al_2O_3 particles and etching was performed by Marble's reagent.

The Microstructure of welds was studied by Meiji light microscope and SeronTech AIS2300C scanning electron microscope.

The value of $\delta -$ ferrite in microstructure of welds was gauged by Clemex. Depth and width of welds were measured by sterio microscope.

3. Results and Discussions

Fig. 4. shows welded sections specifications after etching with using different shielding gases.

As it illustrated in Fig.4 and Fig.5, welding penetration of the specimen which welded by pure Ar was 2.90mm.

These results show that adding 20%He to Ar gas for making 80%Ar +20%He shielding gas will increase welding penetration to 3.1mm.

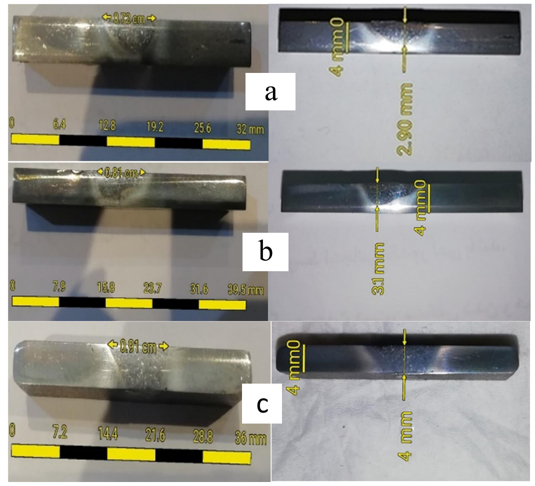

Fig. 4. Weld depth and width affected by different shielding gases: a) Pure Ar, b) 80% Ar + 20% He, c) Pure He

The results are summarized in (Fig. 5.).

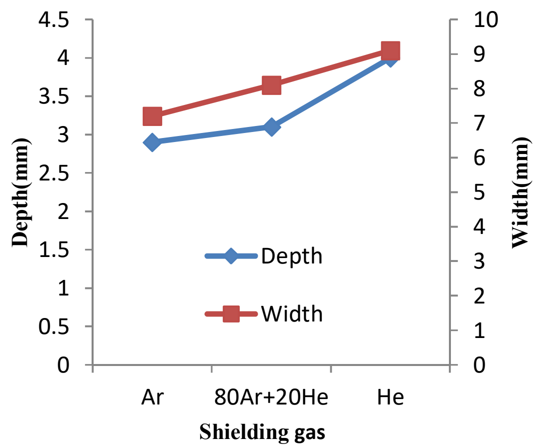

Fig. 5. Variation of weld depth and width versus changes in shielding gas.

The highest penetration was obtained more than 4mm by using pure He and excess penetration was seen in this specimen. Moreover, weld width of the specimen which was welded by pure Ar obtained 7.2mm. It was increased to 8.1mm in the specimen which was welded by Ar80%+He20% and the widest weld which obtained by pure He was 9.1mm. Based on the previous results [17, 10]. helium can produce deeper penetration than argon. Due to produce hotter arc, pure helium makes more heat input than argon. Pure argon generates cooler arc which leads to produce smaller welding pool and lower penetration. So, wider and deeper welds can be produced by using helium as shielding gas [10, 12]. Furthermore, shielding gases with a higher rate of thermal conductivity such as pure helium will produce welds with a wider and deeper penetration.While shielding gases with a lower rate of thermal conductivity like pure argon have a shallower penetration [18].

Fig. 6. shows the microstructure of weld zone for three different specimens which were welded by different shielding gases.

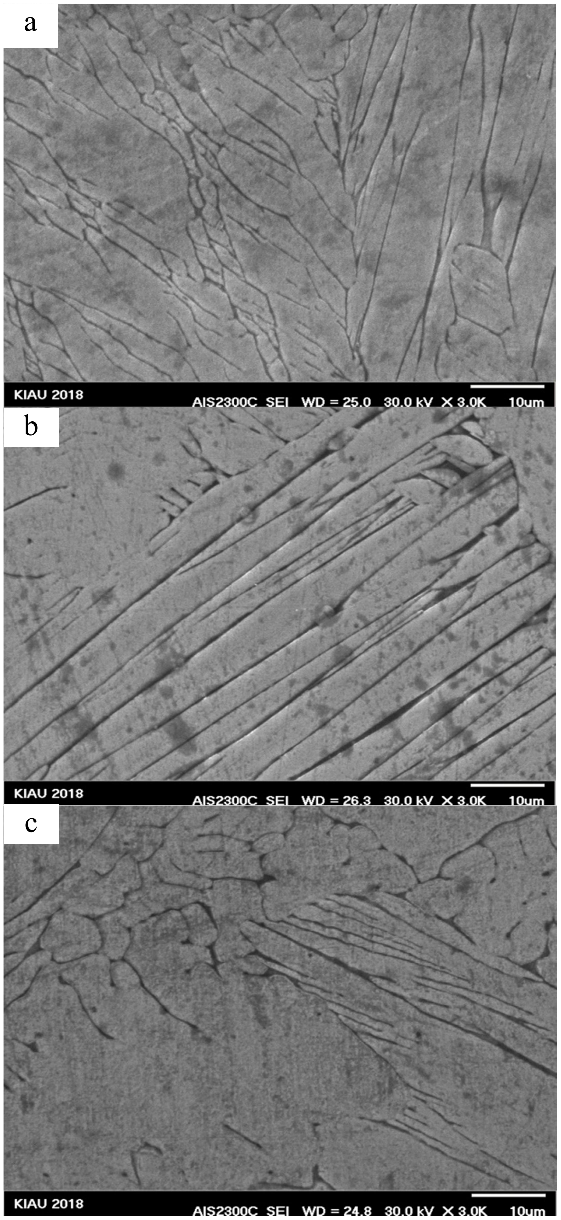

Fig. 6. Microstructure of weld zone welded by different shielding gases: a) Pure Ar, b) 80% Ar + 20% He, c) Pure He.

As can be seen in Fig. 6., microstructure of weld zone consists of $\delta-$ferrite in the martensitic matrix. The perivious studies [13-16] also confirmed this result. The percentage of $\delta-$ferrite in the weld zone of each specimen is measured and presented in (Fig. 7.). As it shown in Fig. 7., $\delta-$ferrite value decrease by addition of He in shielding gas. The highest amount of $\delta-$ferrite was about 16.6% which was obtained by using pure Ar as shielding gas.

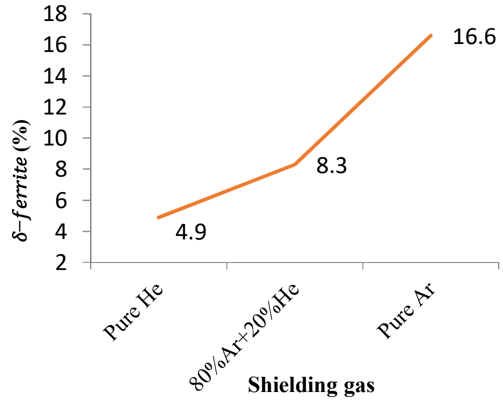

Fig. 7. Variation in $\delta-$ferrite value by changes in shielding Gas.

It was about 8.3% in the specimen which was welded by 80% Ar + 20% He. The lowest value of $\delta-$ferrite was achieved by using pure He as shielding gas. Reduction of $\delta-$ferrite in the weld zone can be related to the higher heat input which is produced by using He. Use of He leads to increase in HI and decrease in cooling rate. Consequently, $\delta-$ferrite value will reduce. This result was observed in the research of Sufizadeh [16]. The results of hardness measurements are presented on Fig. 8. and Fig. 9.

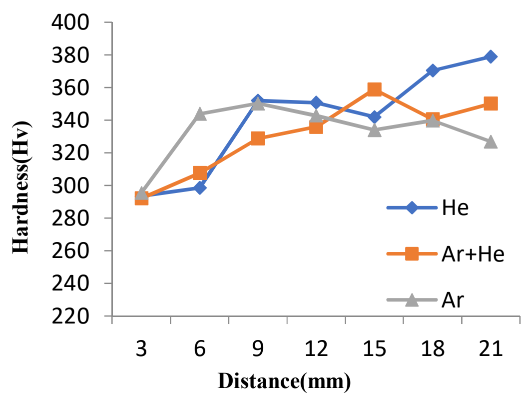

Fig. 8. Distribution of hardness versus distance.

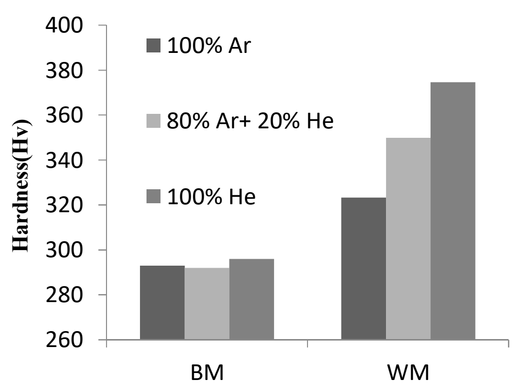

Fig. 9. Average of hardness in weld and base metal.

The hardness profile for the examined specimens shows that hardness value increase by moving from base metal to weld zone. Hardness of base metal is similar for all 3 specimens. It was about 293Hv. Average of hardness in weld zone shows more difference. The highest average of hardness in weld zone was gained by using pure He. The average of hardness in this specimen was 374Hv. It was about 350Hv for the specimen which was welded by 80% Ar + 20% He. The lowest average of hardness in weld zone was about 333Hv which was achieved by using pure Ar as shielding gas. These results are also shown in Fig. 9. Average of hardness stays almost constant in base metal for all 3 specimens. It occurs due to the distance of base metal from the heat of welding. The effect of $\delta-$ferrite phase on hardness of weld was investigated by Najafi et al. [19]. They declared that for as much as $\delta-$ferrite is a soft/ductile phase, it decrease the hardness of weld. According to the mentioned contents and the results of Fig.7, hardness increment of weld zone can be related to the lower amount of $\delta-$ferrite in the martensitic matrix. Moreover, higher value of $\delta-$ferrite in the microstructure was the agent of reduction in weld hardness of the specimen which was welded by pure Ar.

4. Conclusions

1. The He as shielding gas was produced the deepest and widest weld.
2. The lowest value of weld width was 7.2mm and the lowest penetration depth was 2.90mm which were achieved by using pure Ar.
3. The highest amount of $\delta-$ferrite in the microstructure of weld was about 16.6% and it was obtained by using pure Ar. 8.3% of $\delta-$ferrite was apperied in the microstructure of the specimen welded by 80% Ar + 20% He.
4. The lowest value of $\delta-$ferrite in the microstructure of weld was about 4.9% which was produced by using pure He.
5. Maximum hardness value of weld was gained by using pure He. It was about 370Hv. This value decrease slightly to 350Hv in the weld zone of specimen which was welded by 80% Ar + 20% He.
6. The lowest hardness of weld was about 333Hv and it was achieved by pure Ar welding.

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