Journal of Welding Technology
P-ISSN: 2716-1471 | E-ISSN: 2716-0475
http://e-jurnal.pnl.ac.id/Welding_Technology

Effect of Shallow Cryogenıc Heat Treatment on Metal Inert Gas Weldıng Zone of S 355 J2 Steel

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Article Processing Dates:
Received 2022-02-11
Accepted 2023-05-06
Available online 2023-06-30

Keywords:
Shallow cryogenic heat treatment
Metal inert gas welding
Welding zone
Pressure vessels
S355J2 Steel

Abstract

Metal inert gas welding (MIG) is generally conducted in the pressure vessel industry due to its high quality and easy automation. S355 J2 steel is used widely in this industry for its proper welding properties. To carry out and obtain high melting efficiency for satisfactory mechanical properties according to welding parameters, sometimes heat treatment is applied to materials, but generally it is not common in welding industry. In this study the effect of conventional heat treatment and shallow cryogenic heat treatment effects to the mechanical properties of welding zone of S 355 J2 steel welded with MIG is investigated. The charpy impact tests have been carried out. The welding plate is prepared according to this purpose and it is cut for impact test samples 10 X 10 x 55 mm. Totally 30 samples are prepared for 5 processes. Process 1: 6 samples for without heat treatment. Process 2: 6 samples for normalization-quenching in water. Process 3: 6 samples for normalization-quenching-tempering. Process:4 6 samples for normalization-shallow cryogenic treatment. Process 5: 6 samples for normalization-shallow cryogenic treatment-tempering. Notch of impact test samples are prepared just in the middle of the welding zone (2 sample for each process) , HAZ (2 sample for each process) and basemetal (2 sample for each process). The hardness values are taken from base metal, heat affected zone and welding area respectively. Hardness values and impact test results are compared. As a result, generally, it has been observed that shallow cryogenic heat treatment have a remarkable effect on toughness, despite a little decrease in hardness. The toughness of welding zone is increased approximately %40 and HAZ % 5 after cryogenic heat treatment. The hardness of WZ is increased approximately % 5 after cryogenic heat treatment, no significant change is observed in HAZ.

1. Introduction

In recent years, there has been a great interest to improve hardness, fatigue, and impact behavior of metals especially creating compressive residual stresses on surface of steel elements. Residual stresses are stresses which can stay in the element/material however the primary cause of stresses are cleared off. The main reasons for the residual stress are: (1) Failures because of stress corrosion, fatigue or embrittlement of hydrogen. (2) Because of the service, process and storage circumstances of that component.

Residual stresses are formed through load, temperature effects or both. They occur when different kinds of like shot peening, grinding, welding, non uniform plastic deformation subjected to cold working, surface hammering, phase transformations and high temperature differentiations. Increasing of tensile residual stresses on steels causes to fatigue failure. In contrast, an increase in compressive residual stress at the surface of the steel decreases fatigue cracks propagation rates of the component. For that reason, interest and need are emerged in the improvement of compressive residual stress [1].

Residual stresses affect design field remarkably. It can cause the increase in fatigue resistance but also develops the dimensional stability. It can also affect the resistance against cracking due to stress corrosion positively. Residual stresses may be categorized into the following two types: microstresses and macrostresses. There are three types of residual stresses. First, macrostresses remain homogenous over a huge number of grains, and equilibrium of forces is assumed over a huge number of crystals. The second type of stress remains homogenous within one grain, and the forces are assumed to balance together with adjoining grains. Finally, the third type is homogenous over some interatomic distances, and the internal forces around the crystalline defects remain equilibrium. The second and third types of stress jointly form the microstresses [2].

Metal inert gas welding (MIG) is generally conducted in the pressure vessel industry due to its high quality and easy automation. S355 J2 steel is used widely in this industry for its proper welding properties [3].

To carry out and obtain high melting efficiency for satisfactory mechanical properties according to welding parameters, sometimes heat treatment is applied to materials, but generally it is not common in welding industry [4]

Classic heat treatment is a process or combination of processes with heating and cooling of a metal or alloy in the solid state to attain certain proper conditions or properties. It comprises; heating steels and alloys to a certain temperature, holding there for a time period and then cooling at different temperatures with the aim of changing their structure and properties. It consists of the following operations [5]: (1) Heating to a certain temperature. (2) Soaking for certain period to complete desirable structural changes. (3) Cooling at a specified rate to a predefined temperature.

The samples that are subjected to this treatment procedure are called classic heat treatment (CHT) process. It involves quenching in a hardening media (water, oil, air) at predefined temperature for a specified duration.

Samples are subjected to the tempering proces then. ASM Metals Handbook defines tempering as "Reheating hardened steel to some temperature below the eutectoid temperature to decrease hardness and also to increase toughness."

A cryogenic treatment is the process of treating workpieces to very low temperatures (i.e. below −180 °C deep cryogenic treatment, in shallow treatment to −80 °C) for the purpose of removing residual stresses and enhance wear resistance in metal and metal alloys. Additionally, it is also conducted to improve corrosion resistance [6].

The process is applied in a wide range from industrial tooling to the improvement of musical wires. It ensures longer part life, less failure due to cracking, improved thermal properties, better electrical properties including less electrical resistance, reduced coefficient of friction, less creep and walk, improved flatness, and easier machining [7].

Cryogenic treatments are popular method improved in recent years for transforming retained austenite before tempering and remove the problems related to austenite stabilization. Retained austenite transformation into martensite can remove residual stress in a great amount. This process has a great effect on the steel component's usability. Cryogenic treatments can produce a molecular change in steel alloys, transforming most of the retained austenite into martensite, providing smaller, denser and a more uniform structure than austenite [8].

Cryogenic treatment can be categorized in two; (1) Shallow cryogenic treatment temperature regime is from 0 ℃ to 80℃. (2) Deep cryogenic treatment temperature regime is from 80℃ to 196℃. In this entry, the effect of two cryogenic treatments, namely shallow cryogenic treatment (SCT, 80℃ for 5 hr) and deep cryogenic treatment (DCT, 196℃ for 24 hr) on surface residual stress of some steels are studied [9].

The process has a wide range of applications from industrial tooling to the improvement of musical wires. Including longer part life, less failure due to cracking, improved thermal properties, better electrical properties including less electrical resistance, reduced coefficient of friction, less creep and walk, improved flatness, and easier machining are some of the benefits [10].

Significant studies have been contributed to technical literature in recent years about welding and heat treatment/cryogenic treatment relationship. Some of them are represented below.

M. Park and colleagues studied on the effects of post weld heat treatment for welded high-Mn austenitic steels using the submerged arc welding method and explained the mechanisms of impact toughness improvement by analyzing the microstructure and deformation behavior through the instrumented Charpy impact test and EBSD analysis [11]. H. Nam and colleagues focused on gas tungsten arc weldability of stainless steel 304 using CoCrFeMnNi filler metals for cryogenic applications, and excellent tensile strengths at lower temperature degrees attributable to martensite transformations and deformation twins are obtained respectively [12]. H.W. Eom and colleagues investigated effect of cooling rate on the microstructure and cryogenic impact toughness of heat effected zone of % 9 Nickel steel and concluded worthy results [13].

X. Fan and colleagues investigations on mechanical properties of cryogenic high manganese steel joints filled with nickel-based materials by hielded metal arc welding (SMAW) and submerged arc welding (SAW) [14], J. Shang and colleagues studies on the effect of cerium on microstructure and microsegregation behavior of novel cryogenic high-Mn austenitic steel weld metal [15], H.T. Serindağ and colleagues experiments on microstructural and mechanical properties of gas tungsten arc welded thick cryogenic 9% Ni alloy steel butt joint [16], C. Cui and colleagues studies on The effects of post-weld aging and cryogenic treatment on self-fusion welded austenitic stainless steel [17], and Y.Shen studies on the influence of cryogenic and heat treatment on the mechanical properties of laser-welded AZ91D alloy [18] are some of the most noteworthy researchs in the field.

The purpose of the study is to investigate the difference in the hardness and toughness values of MIG welded S 355 J2 steel which is commonly used in pressure vessels before and after conventional and cryogenic heat treatment methods.

When the previous studies and literature is examined, it is not met any study related to cryogenic heat treatment with the MIG welded S 355 J2 steel together. This makes this study an original one.

2. Materıals And Method

In this study the effect of conventional heat treatment and shallow cryogenic heat treatment effects to the mechanical properties of welding zone of S 355 J2 steel welded with MIG is investigated. 6 plates are welded prepared as 400 (200x2) x 200 x 12 mm. Dimensions of one plate is 200 x 200 x 12 mm. Total 12 plates were ready. The welding plate is prepared according to this purpose and it is cut for impact test samples 10 X 10 x 55 mm.

Charpy impact tests were performed in the temperature 20℃ with automatic ZWIC impact test machine of 750 J capacity. The charpy impact tests have been carried out according to ASTM E23-02 "Standart Test Methods For Notched Bar Impact Testing Of Metallic Materials" (10 mm X 10 mm X 55 mm, 45 V-notch of 2 mm. depth) [19].

Charpy impact specimens in HAZ were taken at a distance of approximately 5 mm from the center of welding zone line (WL) (Fig. 1).

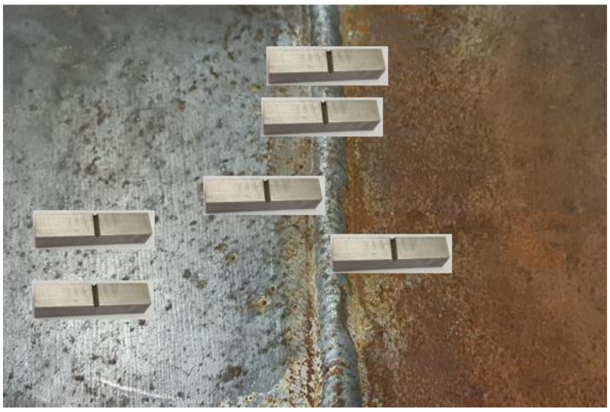

Fig. 1. Representative Fig.s of charpy impact test samples taken from welded plates according to ASTM E23-02 “Standart Test Methods For Notched Bar Impact Testing Of Metallic Materials”.

Notch of impact test samples are prepared just in the middle of the; welding zone (2 sample for each process), HAZ (2 sample for each process) and base metal (2 sample for each process).

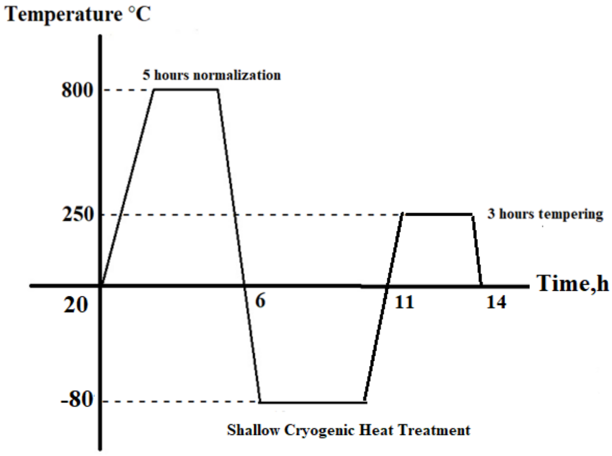

Fig. 2. Overall Heat/Shallow Cryogenic Treatment Process Diagram

Totally 30 samples are prepared for 5 processes (Fig. 2). Process 1: 6 samples for without heat treatment. Process 2: 6 samples for normalization-quenching in water. Process 3: 6 samples for normalization- quenching-tempering. Process:4 6 samples for normalization-shallow cryogenic treatment. Process 5: 6 samples for normalization-shallow cryogenic treatment-tempering

The hardness values are taken from base metal, heat affected zone and welding area respectively [20]. Hardness values and impact test results are compared.

S 355 J2 is a micro alloyed structural steel suitable for pressure vessel production (Table 1). The steel possesses an exceptable weldability; max CEV =0.47

Table 1. S 355 J2 Steel Specifications

Chemical Composition								
C %	Si %	Mn %	P %	S %	Cr %	Ni %	V %	Fe %
0,2	0,55	1,6	0.035	0.040	-	-	0,15	Remain

Mechanical Properties			
Yield Strength (MPa)	Tensile Strength (MPa)	Hardness (HB)	Impact Toughness (J)
355	490-630	150-190	-20°C 27 J

Metal Inert Gas (MIG) welding is an arc welding process that uses a continuous solid wire electrode heated and fed into the weld pool from a welding gun. also known as MAG (Metal Active Gas) and in the USA as GMAW (Gas Metal Arc Welding), is a welding process that is now widely used for welding a variety of materials, ferrous and non ferrous.

The essential feature of the process is the small diameter electrode wire, which is fed continuously into the arc from a coil. As a result, this process can produce quick and neat welds over a wide range of joints. For MIG welding; % 25 Carbon Dioxide + % 75 Argon is used as shielding gases. Wire composition is presented in table 2.

Table 2. MIG Wire Composition

Chemical Composition								
C %	Si %	Mn %	P %	V %	Cr %	Ni %	Mo %	Fe %
0,06-0,15	0,80-1,15	1,40-1,85	0.025 max.	0.03 max.	0,15 max	0,15 max.	0,15 max.	Remain

Process parameters are detailed: Welding current (A) 230. Travel speed (mm/s) 8. Welding voltage (V) 24.

3. Results and Dıscussıon

As a general result, it has been observed that shallow cryogenic heat treatment have a remarkable effect on toughness, despite a little decrease in hardness. Obtained results are shown on table 3.

Table 3. Impact Test and Hardness Values Results

Process	Impact Energy (J.) Base Metal (BM) 20°C	Impact Energy (J.) HAZ 20°C	Impact Energy (J.) Welding Zone (WZ) 20°C	HB (BM)	HB (HAZ)	HB (WZ)
1	102-105	112-115	105-110	195-190	230-230	215-218
2	89-86	85-89	87-92	223-230	235-240	235-230
3	90-92	102-105	105-97	200-200	205-208	220-234
4	92-95	120-121	155-151	225-224	229-236	237-239
5	100-102	115-114	150-146	223-223	214-215	232-227

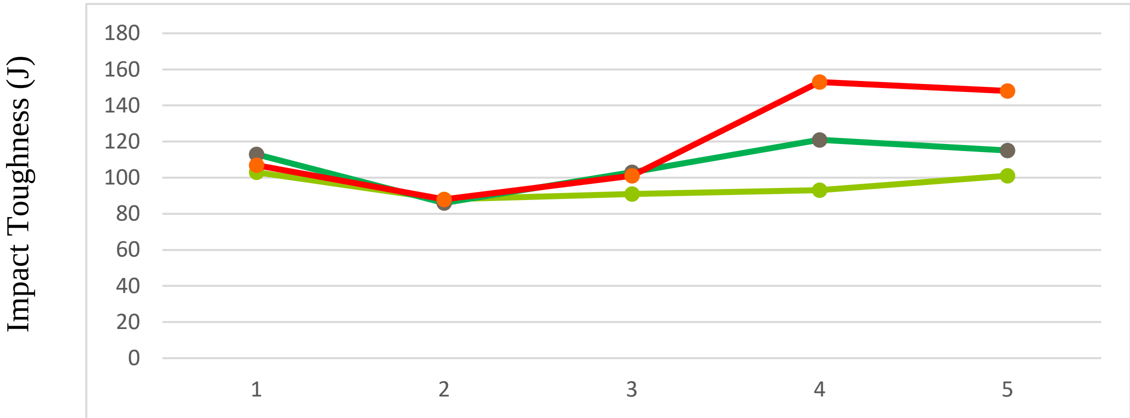

Fig. 3. Impact Toughness Test Results Change According to the Processes
(Red: Welding Zone, Dark Green: Heat Affected Zone, Jade: Base Metal)

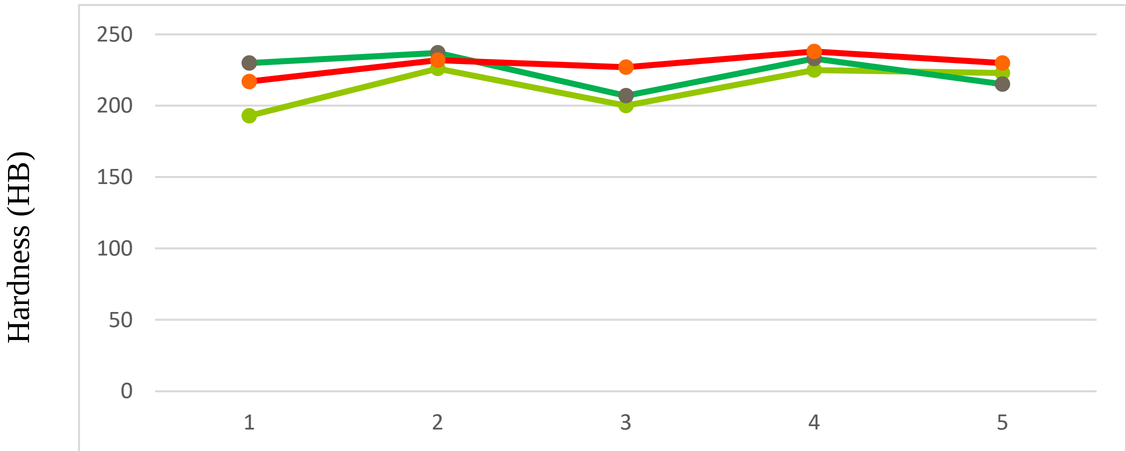

Fig. 4. Hardness Values Change According to the Processes
(Red: Welding Zone, Dark Green: Heat Affected Zone, Jade: Base Metal)

When Fig. 3 is examined, it could be seen that process 4 (normalization-shallow cryogenic treatment) and process 5 (normalization-shallow cryogenic treatment-tempering) are the most effective treatments on increasing the toughness.

Hardness values did not change significantly by treatments, but welding zone hardness value increased a little bit in process 4 (normalization-shallow cryogenic treatment) according to Fig. 4.

Hardness values increase as the quenching temperature decreases and tempering reduces hardness by increasing toughness, so significant increase is not observed in hardness values in processes.

4. Conclusion

Beside conventional heat treatment, cryogenic heat treatment has a remarkable effect on mechanical properties of MIG welding zone of S 355 J2 steel. SCT increases the hardness, SCT + tempering give a significant value of hardness and toughness, despite decreased hardness. Welding zone hardness values are observed higher than HAZ's measured values. The service temperature of welded S 355 J2 steel structure can be between -100 and -150°C. SEM images and EDS analyses can give clearer and better results as a future study. (recommendation). Submerged arc welded steels can also be subjected to cryogenic treatment and tested. (recommendation)

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