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Improvement of Stress Corrosion Cracking of Stainless-Steel Welded Pipes by Ultrasonic Stress Relief Treatment

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Abstract

Inert Gas Tungsten Arc Welding (GTAW) process is one of the most widely used welding processes in which material is prone to stress corrosion cracking (SCC). Stress corrosion indicates cracking due to combined effect of stress and corrosion. Many rupture incidents have occurred due to this type of cracks. Effect of ultrasonic waves were studied on GTAW welded SS316L metal, in this paper. Two samples were healed by post weld ultrasonic treatment, two samples by post weld heat treatment and two were considered as control samples with no post treatment. Residual stress of all six pieces were measured by XRD method. Afterwards, samples were placed in corrosion environment. Results show that residual stress was decreased to 54.3% using heat treatment whereby this decreased to 58.7% by ultrasonic waves. It was also shown that untreated samples cracked after 720 hours, while no crack was seen in post weld ultrasonic treated samples.

1. Introduction

Stress corrosion was identified for the first time in 1965 in Louisiana, USA, during the failure analysis of a gas transmission pipeline. However, comparing the fractographic and metallographic features of SCC destruction with archived information on the destruction of pipelines showed that the first destruction due to this corrosion occurred in 1957 in Battle in America. [1-3]. As its name implies, SCC indicates cracking caused by the combined effect of corrosion and stress. Stresses may be presented as applied or residual stresses. Cold forming and deformation, welding, heating operations and machining are among the factors that create residual stresses. The magnitude and importance of such tensions are often overlooked. With SCC, most of the surface is usually safe from attacks, but small cracks penetrate deep into the material. In the microstructure, these cracks can have intergranular or grain boundary morphology. In macro dimensions, SCC fractures have a brittle appearance. Temperature, pressure, type, concentration, level of activity of aggressive agents, pH, electrochemical potential, solution viscosity and stirring (lack of stillness) are among the environmental parameters that affect the crack growth rate [4-6].

SCC is the result of the simultaneous application of tensile stress and corrosive environment on the metal, and it starts from the growth of very small cracks over several years and finally ends in a complete rupture [7-10]. So far, there have been many rupture incidents caused by these types of cracks. This type of corrosion is one of the common types of corrosion in which, in addition to the corrosiveness of the environment, the mechanical stress factor is also a necessary condition for its occurrence. In this corrosion, the metal that is exposed to the corrosive environment either has some residual stress, or the solution is under stress based on the working conditions of the part. These cases cause the formation of cracks in the system, and the presence of these cracks in the part causes its deterioration. In fact, stress corrosion is the deterioration of a metal or alloy that is located in a corrosive environment and is under relatively small but continuous tensile stresses [11-14].

In order for stress cracking to occur, the simultaneous presence of three factors is necessary, which are:

• Corrosive environment [15-16].

• Presence of a metal or alloy sensitive to this type of cracking [16-17].

• Existence of tensile stress on metal or alloy [18].

For example, hot aqueous chloride solutions are able to create cracks in stainless steels with a significant speed, while they do not have such an effect on carbon steels, aluminum and other non-ferrous alloys. In this way, it can be said that every corrosive environment is not able to be effective on all alloys and cause stress cracking in them, but every corrosive environment is capable of creating stress cracking only on a limited number of metals and alloys [19].

Regarding the effects of ultrasonic hammering in order to reduce residual stresses on various metal materials, a lot of research has been done and the reduction of tensile stress has been proven. It has not been done so far, which will be addressed in this research.

Pipes made of austenitic stainless steels in refineries and petrochemicals and in the vicinity of chlorine ions are severely attacked by corrosion to intensify this action next to H2. The oxide of the cream, which has a protective role, is attacked by the negative ion of chloride and is destroyed. This operation is usually done locally and on the surface of the steel, pitting corrosion, which includes small and large holes, is created. These holes created when external stress is applied will be the source of stress concentration. These cracks are intergranular or grain boundary type. Usually, if the stainless steel has become sensitive in some way due to welding or as a result of heat treatments, then the probability of grain boundary type of failure increases, while most of the recorded cracks are of intergranular type that disappear by themselves. Having a tension control mechanism and tearing of oxide layers for crack progression is telling [20-21]. The steps that can be carried out in this research will include the preparation of the work piece, stress relief by ultrasonic method and thermal processes, placing it in the tested solution, analysis and testing [22].

One of the important topics in the field of welding in engineering structures is the discussion of reducing residual stresses in welding lines and improving the quality of welding. Residual stresses reduce the load bearing limit, the life of welded joints and change the forms in welded structures. Residual stress is the stress that remains in the body and is in balance with its surroundings. Therefore, it is very important to know its amount in design. Residual stresses are self-balanced stresses that are trapped in the part due to production processes such as rolling, welding, casting, etc. and can have a positive or negative effect on the life of the parts [23-24]. In different sources, various methods are defined for the division of residual stresses, which divided to thermal and mechanical processes. **Figure 1,** shows various processes for pipe production. Welded Pipes have more residual stress in comparison with other products.

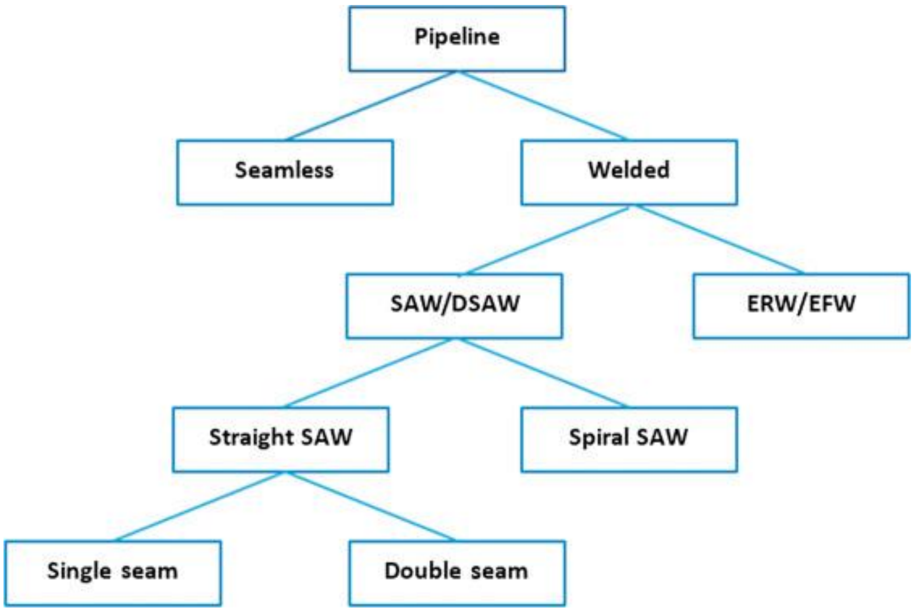

Figure 1. Various processes for pipe production.

2- Materials and Methods

The steps of this research are shown in **Figure 2.** The sample selected from the austenite group, which is stainless steel according to ANSI, which chemical composition and mechanical properties are shown in **Tables 1 and 2.** After preparation, the pipes were welded by arc welding method with tungsten electrode and argon shielding gas. **Figure 3** shows the image of the welded pipe before cleaning.

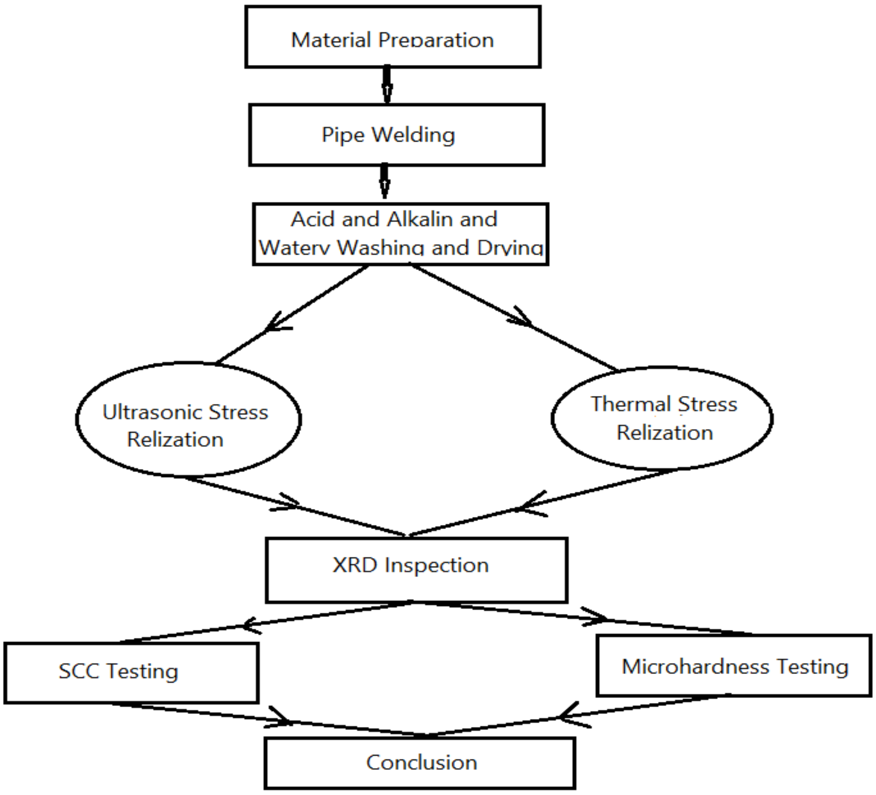

Figure 2. Flowchart of the research method

Table 1. Chemical composition of 316 L stainless steel

UNS	Type	%C	%Si	%Mn	%P	%S	%Ni	%Cr	%Mo	%Cu
S 316	316L	≤ 0.03	≤ 1	≤ 2	≤ 0.04	≤ 0.03	10-14	16-18	2-3	≤ 0.75

Table 2. Mechanical Properties of 316 L stainless steel

TS (MPa)	YS (MPa)	El%	Hardness (BHN)
485	170	40	95

Figure 3. Welded pipe before cleaning.

After degreasing, descaling, neutralization and washing, the pipes were subjected to stress relief by ultrasonic and thermal methods. Ultrasonic pinning equipment includes a source of generating ultrasonic electric waves, a transmitting transducer, and an impact tool. This equipment can be used in all types of welding joints. **Figure 4** shows an example of ultrasonic pinning equipment.

Figure 4. Penning ultrasonic equipment

Then, in order to determine the amount of residual stress, the prepared samples were tested by XRD method. After that, the samples were subjected to SCC test according to NACE TM0177 standard.

3. Results and Discussion

3-1- The results of the tensioning operation

Figure 5 shows and compares the amount of residual stresses in samples without stressing, thermal stressing and ultrasonic stressing. According to the figure, the amount of residual stress in the thermally stressed sample is 58.7% and in the ultrasonically stressed hel sample, it is 54.3% of non-stressed pipes. This comparison shows that, in addition to further reducing the residual stress, ultrasonic stressing reduces the risk of pipe warping due to the high temperature of thermal stressing.

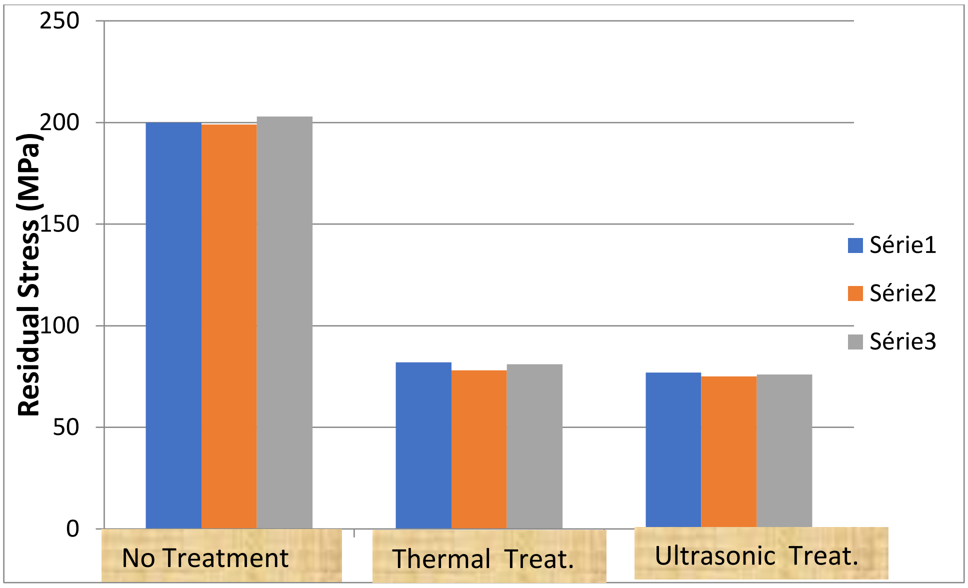

Figure 5. Residual stresses in samples without stress relief, thermal and ultrasonic stress relief.

3-2- The results of the SCC test

Two unstressed and stressed samples were placed in the corrosion environment using ultrasonic stress relief; For the SCC test, sampling was done from the pipe; Sampling was selected and cut longitudinally from the weld, the samples were subjected to load in the ASTM G39 (2016) test; The graph of temperature changes during the SCC test is shown in **Figure 6**.

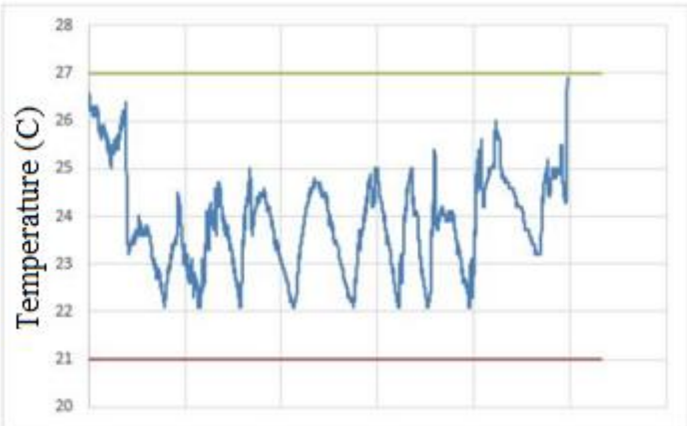

Figure 6. Diagram of temperature variation during the SCC test

The result of the SCC test shows that in the non-stressed sample, the part cracked after 720 hours of being in the corrosive environment, **Figure 7** Also, the SCC test showed that the ultrasonically stressed sample cracked after 720 hours. There was no cracking caused by the corrosive environment, but in the unstressed sample, the crack started at the boundary between the weld and the heat-affected area and entered the weld metal. This phenomenon is due to the lack of integration and changes in the grain size of the HAZ area **[26]**.

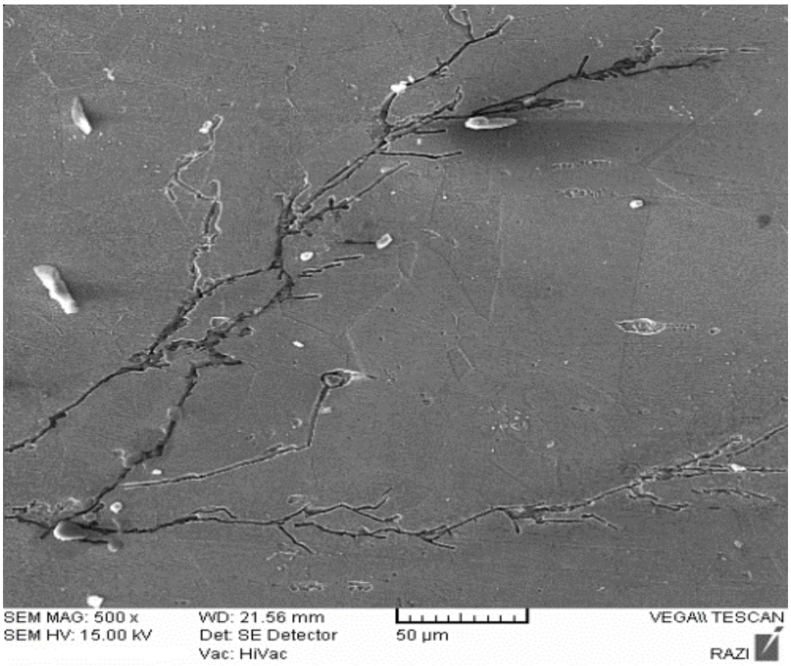

Figure 7. Cracks created after 720 hours of placing the sample without stress relief

4 - Conclusion

- The results of XRD (maximum amount of residual stress) of the sample without stress removal treatment show that the GTAW welding process has caused the maximum residual stress to be 7.204 MPa.
- The results of XRD (maximum amount of residual stress) of the sample with thermal stress relief show that thermal stress relief increases the maximum value of residual stress resulting from GTAW welding from the average value of 7.204 MPa before stressing. It has decreased to an average value of 88.06 MPa after stressing.
- The results of XRD (maximum value of residual stress) of the sample with ultrasonic stress relief show that ultrasonic stress relief reduces the maximum value of residual stress resulting from GTAW welding from the average value of 7.204 MPa before stressing. It has decreased to an average value of 21.83 MPa after stressing.
- Reduction of residual stress in ultrasonic method is more than thermal stressing.
- The sample stressed under the ultrasonic method - under the NACE standard SCC test - did not experience any cracking after 720 hours due to being placed in a corrosive environment.
- Ultrasonic stressing has a favorable effect on corrosion resistance in 316L stainless steel.

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