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# Effects of post weld heat treatment on residual stress and mechanical properties of GTAW: The case of joining A537CL1 pressure vessel steel and A321 austenitic stainless steel

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ABSTRACT

In this paper, the effect of different temperatures of post weld heat treatments on the residual stress and mechanical properties were investigated for dissimilar joint of ASTM A537CL1 pressure vessel steel to AISI A321 austenitic stainless steel. These joints are commonly used in high temperature services such as boilers, pressure vessels, heat exchangers in petrochemical, oil and gas industries, etc. For this purpose, gas-tungsten arc welding process with ER308L filler metal with diameter of 1.8 mm was used. Then, post weld heat treatment (PWHT) was carried out at 480, 560, 620 and 680 °C for 75 min on the samples. The optical microscope and scanning electron microscope (SEM) were used to study the microstructure and fracture surface of the welded samples. Also, the mechanical behavior of the joint was evaluated by tensile, impact and microhardness tests. The residual stresses of the samples were evaluated with ultrasonic technique. Results showed that the post weld heat treatment had not any significant effect on microstructure of different regions of the joint. Mechanical properties such as ultimate tensile strength and hardness were reduced after post weld heat treatment process. In addition, results of residual stress measurements of the joints showed that the welded sample (without being heat treated) had maximum residual stress, while the sample which was heat treated in 620 °C had minimum residual stress. Impact energy was reduced 52% at this temperature and it was found that 620 °C was the optimum temperature.

## 1. Introduction

Nowadays, one of the most important objectives of industrial designers is optimum utilization of parts and informing of functionality, reliability and performance parts so as to be able to make the best use of the existing parts. There are many factors affecting the quality of welded parts and residual stress in components is undoubtedly one of the most important factors [1–3]. Welding is widely used in many critical applications such as oil, gas, hulk, pressure vessels, petrochemical, marine docks, power plants, nuclear reactor, military and aerospace industries. In these cases, residual stresses are very important in such critical applications. There are different methods for reducing the residual stresses and the post weld heat treatment is one of the most common techniques for relieving of residual stresses [4, 5]. Reducing the effect of residual stresses induced by welding and improvement the mechanical properties are the primary purposes of PWHT. Often, heat treatment in a critical temperature range is improper and therefore stress

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relieving is mostly done under the critical limit.

In recent years, some studies have been conducted on the effect of PWHT on weldments [6–10]. Smith and Pistorius [11], for instance, investigated the effect of a long post weld heat treatment on the integrity of a weld joint in a pressure vessel steel. They observed that the microhardness and strength of weld and HAZ zones reduced and the toughness increased after PWHT. In addition, Cho et al. [12] studied the residual stress and post weld heat treatment of multi pass welds. They found that the maximum residual stress in the weld metal was 316 MPa which decreased to 39 MPa after post weld heat treatment. Aloraier et al. [13] used flux-cored arc welding (FCAW) process to avoid the use of post weld heat treatment after the process of manufacturing and repair. The results showed that when welding with 70% coincidence and by FCAW is applied, the microstructure and hardness are improved. Brito et al. [14] investigated the effects of post weld heat treatment on submerged arc welded ASTM A537 pressure vessel properties. Toughness in the weld metal zone increased and in HAZ and base metal decreased. They claimed that this could be due to the deposition of some compounds in these zones after PWHT. Sterjovski et al. [15] studied fatigue and toughness behaviors on the post weld heat treated steels and concluded that the impact energy decreased in base metal by increasing the post weld heat treatment time. Precipitation of brittle phases, such as carbides, caused fractures to become brittle. In another study, Sterjovski et al. [16] investigated the evaluation of cross-weld properties of quenched and tempered pressure vessel steel by submerged arc welding process before and after PWHT. They found that hardness reduced by post weld heat treatment in all zones and ductility increased in the weld metal. Lochhead et al. [17] studied the effects of heat treatment on tensile properties of ASTM A533 quenched and tempered steel and concluded that the yield and tensile strengths reduced by post weld heat treatment. In fact, ductility and toughness increased and yield and tensile strengths decreased by increasing time and temperature of heat treatment.

Based on the above studies, the purpose of this study is to determine a suitable PWHT temperature to reach proper microstructural and mechanical properties. According to the previously mentioned studies, it can be claimed that the joint of A321 stainless steel to A537CL1 pressure vessel steel has different applications in oil and gas industries. Therefore, in the present study the effect of PWHT process was investigated on microstructure and mechanical properties of A321 to A537CL1 steels joint.

## 2. Experimental procedures

The chemical compositions and microstructures of ASTM A321 and ASTM A537CL1 steel sheets as base metals and ER308L steel as filler metal are presented in Table 1 and Fig. 1.

As can be seen in Fig. 1, the microstructure of A321 steel contains austenite grains and some fibers of delta ferrite. Also A537CL1 steel showed normal structure of cold rolled carbon steels including elongated ferrite and pearlite phases.

As shown in Fig. 2, base metals were prepared according to AWS D1.1 standard. The welding process was done by GTAW method using ER308L filler metal. Welding parameters are shown in Table 2. Heat input of the welding process in each pass was calculated by Eq. (1) in terms of $kJ.mm^{-1}$. In this formula, V is voltage in versus volt, I is the current in versus ampere, S is the speed of GTAW gun in $mm.s^{-1}$ and η is the thermal efficiency, which was considered 0.6 for GTAW process [18].

$$(V.\ I.\ 60/1000.\ S)\eta = Q \tag{1}$$

After the welding, different post weld heat treatments were applied on the welded samples. In this study, a thermo line resistance electric furnace, model V.S.A-F-A 1740-1 (made in USA) was used to apply the post weld heat treatment process. Four samples prepared according to ASM standard were stress relieved at 4 different post weld heat treatment temperatures for 75 min. The different post weld heat treatment cycles were done on samples and shown in Fig. 3. The heat treatment process was done in furnace under argon inert gas atmosphere to prevent any oxide formation on the welded areas. Samples were coded according to heat treatment temperature and are presented in Table 3.

Microstructural changes of different welding areas were studied by metallography methods and then the fracture surfaces of the welded samples were studied by scanning electron microscope (SEM). After final polishing with a combination of water and alumina solution, the samples were etched. Samples were attacked with marble reagent (10 g $CuSO_4$, 50 ml water and 50 ml hydrochloric acid) for A321 stainless steel and Nital 3% (100 ml ethyl alcohol 96% and 10 ml nitric acid) for A537 structural steel. The microstructure and fracture surfaces of all samples were analyzed by IM 420 optical microscope, made by Sa-Iran company and SEM in a LE0440i model XL30. To investigate the effect of post weld heat treatment temperatures on the mechanical properties, tensile, impact and hardness tests were conducted. The tensile test was carried out according to ASTM-E8 standard by an Instron 4486 tensile machine with INSTRON-4486 model (made in UK). For each sample two measurements were carried out. To determine the impact energy of the welded samples, the Charpy impact test was carried out on specimens at 27 °C, according to ASTM E23-00 standard using Santum machine with SIT 300 model. Three measurements were carried out on each sample. Vickers microhardness test was done according to ASTM E-92 standard, perpendicular to the weld metal. To evaluate the distribution of the residual stresses before

**Table 1**
The chemical compositions of base and filler metals (wt. %).

| Materials | C | Cr | Ni | Si | Mn | Ti | Mo | Cu | V | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| ASTM A537CL1 | 0.16 | 0.03 | 0.1 | 0.22 | 1.18 | 0.003 | 0.005 | 0.02 | 0.007 | Balance |
| AISI A321 | 0.06 | 17.6 | 8.7 | 0.58 | 1.22 | 0.374 | 0.09 | 0.02 | 0.12 | Balance |
| ER308L | 0.04 | 22.5 | 10.5 | 0.3 | 1.7 | --- | 0.4 | 0.1 | 0.1 | Balance |