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Research Article

Comparison of Mechanical Properties of Welded and Non-Welded Steels Used in Tankers with ADR

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Abstract

In this study, the mechanical and metallurgical properties of 304, 321 and 316Ti stainless steels used in tankers subject to the European agreement on the Carriage of Dangerous Goods by Road (ADR)[1] and the welding zones formed as a result of joining the mentioned materials with the ceramic-bottom welding method were evaluated. Tensile test was performed on welded and unwelded samples and their mechanical properties were compared. The microstructure of the weld zone and the heat-affected zone (HAZ) of the welded samples were examined by scanning electron microscopy (SEM) and row hardness was obtained using the Vickers hardness method, which is a microhardness method. Finally, the weld areas of the welded samples were examined by radiographic (x-ray) examination method. The tensile strength in non-welded materials was 669 MPa, with the highest in 304 steels. In welded samples, the highest tensile strength was observed as 643 MPA in the 304 steels. Additionally, in the tensile tests of the welded samples, the rupture occurred in the HAZ regions, not in the welded region.

Keywords: Stainless steel, ADR, Tensile test

ADR'li Tankerlerde Kullanılan Kaynaklı ve Kaynaksız Çeliklerin Mekanik Özelliklerinin Karşılaştırılması

Öz

Bu çalışmada, Tehlikeli Maddelerin Karayolunda Taşınmasına ilişkin Avrupa Anlaşması (ADR)[1] tabii olan tankerlerde kullanılan 304, 321 ve 316Ti paslanmaz çelikler ve bahsedilen malzemelerin seramik altlı kaynak yöntemi ile birleştirilmesi sonucunda oluşan kaynak bölgelerinin mekanik ve metalürjik özellikleri değerlendirilmiştir. Kaynaklı ve kaynaksız numunelerden çekme testi yapılarak mekanik özellikleri karşılaştırılmıştır. Kaynaklı numunelerin kaynak bölgesi ve ısı tesiri altında kalan bölgenin (ITAB) mikro yapısı taramalı elektron mikroskobu (SEM) ile incelenmiş ve mikro sertlik yöntemi olan Vickers sertlik yöntemi ile sıra sertlikleri alınmıştır. Son olarak da kaynaklı numunelerin kaynak bölgeleri radyografik (röntgen) muayene yöntemi ile incelenmiştir. Kaynaksız malzemelerde çekme mukavameti 669 MPa ile en yüksek 304 çeliklerinde görülmüştür. Kaynaklı numunelerde ise en yüksek çekme mukavemeti 643 MPA ile 304 çeliklerinde görülmüştür. Ayrıca kaynaklı numunelerin çekme testlerinde kopma kaynağın olduğu bölgede değil ITAB bölgelerinde meydana gelmiştir.

Anahtar Kelimeler: Paslanmaz Çelik, ADR, Çekme Deneyi

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1. Introduction

Tanker is a land vehicle that transports liquid and gas. The majority of liquid and gas transportation on highways is carried out by tankers. These tankers are closely scrutinized from the initial construction stage to the final ultimate product stage. The transported liquids and gases are classified as hazardous substances, if they are flammable or combustible. In case of transportation of hazardous goods on the roads, they must comply with the ADR legislation. ADR legislation is a European agreement that contains rules determining the international road transport of solids, liquids and gases with flammable, explosive and explosive potential. [1]

In this sector, stainless steels have an important place in tanker manufacturing due to their mechanical properties, chemical composition and corrosion resistance.

The usage areas of stainless steels are growing day by day. It is widely used in the food industry, storage tank, kitchen materials, aviation industry, decorative purposes and many different sectors due to its wide advantages. Due to the stable structure of stainless steels, there is no interaction with the product it carries. The wide product range of stainless steels is a significant point for tanker transportation. Thus, it allows the transportation of various liquids. There are about 200 different types of stainless steels. [2] In this article the weldability of multiple austenitic stainless steels was examined. Austenitic stainless steel has very good corrosion resistance, contains high mechanical properties, can be used at low and high temperatures, and is easy to form.

Therefore, it has a wide range of usage area. Among the stainless steels, the most widely used is the austenitic stainless steel. The most commonly used alloy in austenitic stainless steel is 1.4301 austenitic stainless steel[3]. Compared to its price, 1.4301 high quality austenitic stainless steel is preferred due of its chemical composition, mechanical properties, weldability, and corrosion and oxidation resistance. This particular stainless steel is one of the most popular stainless steels due to its quality, availability on the market, and because it is easy to form and weld. Example 1.4301 can be given as the most affordable in terms of cost.

Weld quality is determined by adequate penetration, and a smooth welding profile. These variables are largely affected by the parameters such as, arc voltage, welding progress speed, shielding gas etc.[4],[5].

As a result, connections that provide optimum properties in thin-section parts will be obtained.Until now, many researchers have investigated the effect of selected parameters on penetration in joints made with different welding methods.[6],[7]

In this study, the mechanical properties of welded and unwelded states of different stainless steels were investigated. Welded samples were welded by semi-auto MAG welding method. Destructive and non-destructive methods analysis of the welded areas were made. With this study, it is aimed to minimize the accidents that may occur during transportation of tankers with ADR and the risks that these accidents may pose on human and environmental health.

2. Material and Method

2.1. Welding and Analysis of Steels by Semi-Auto MAG Method BIOH

In this study, 304 (1.4301), 321 (1.4541) and 316Ti (1.4571) steels were welded by semi-auto MAG method. The welding parameters used in the application are given in Table 1. The chemical compositions of 304,321 and 316Ti steels were obtained using the spectrometer foundry master device and these values are given in Table 2.

The dimensions of the main material used for the welded joint were prepared as 300x150x3 mm, and these prepared samples were joined by using (316LSi) welding wire in the size of 300x300x3 mm.

Table 1. Welding parameters of stainless steels.

Welding parameters	
Welding method	Semi-Auto MAG 125
Welding wire material	316 L Si
Wire diameter	1 mm
Current (I)	180-190
Welding speed (cm/min)	58-68

Table 2. Welding parameters of stainless steels.

Quantity of Elements (%)

Material	C	Si	Mn	Cr	Ni	Mo
316LSi	0,011	0,85	1,57	18,5	11,2	2,54
304	0,015	0,556	1,50	17,7	8,27	0,354
321	0,015	0,586	1,45	17	9,30	0,574
316Ti	0,015	0,679	0,909	16,5	10,9	1,99

The schematic representation of the welding of 304, 321 and 316Ti steels is given in Figure 1. In Figure 2, the pre-welding spotting process, the placement of the ceramic substrate, the position of the welding torch and the images of the welded sample are given.

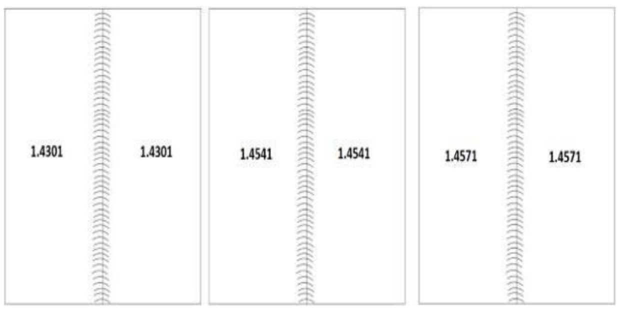


Figure 1. Schematic representation of the welding of stainless steels

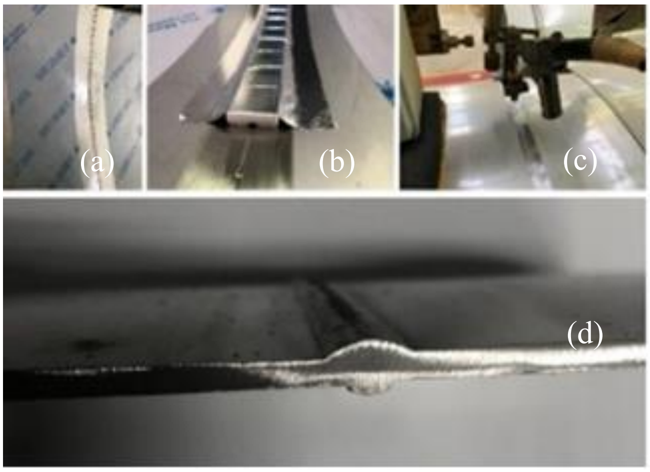


Figure 2. Welding process of Stainless steels; (a) centring, (b) placing of ceramic pad (c) position of welding torch and (d) welded plates.

2.2. Characterization of Welded and Non-Welded Steels

After welding different quality steel plates by semi-auto MAG method, the welding regions were examined by radiographic (x-ray) examination method and scanning electron microscope (SEM). In the welded samples, the row hardness was taken starting from the weld center. In Figure 3, the row hardening areas are marked. Hardness measurements were made using the microhardness method (Vickers, HV) by applying 50 grams of load for 10 seconds.

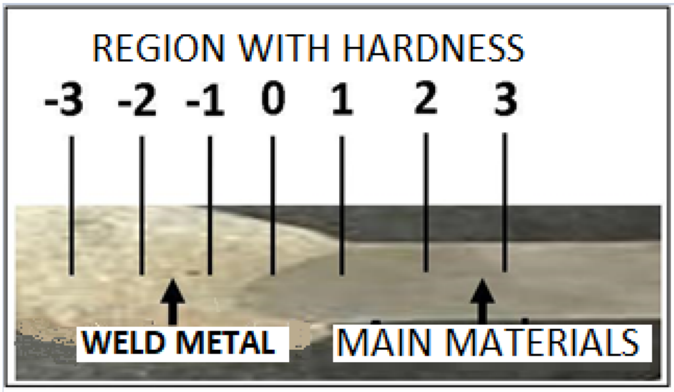


Figure 3. Demonstration of row hardness measurements on welded samples.

Tensile test was applied to both unwelded and welded samples according to EN ISO 4136 standards. It was made by removing samples from 0° and 90° directions to the rolling direction in samples which are not welded. Each experiment was repeated three times and the average was calculated. The schematic representation of the tensile samples extracted from the 0° and 90° directions of the welded and unwelded samples is demonstrated in Figure 4.

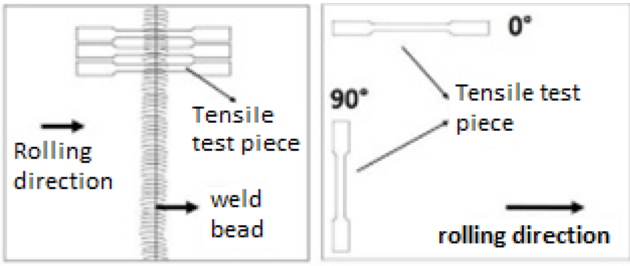


Figure 4. Schematic illustration of the preparation of tensile specimens.

3. Results and Discussion

The results of the radiographic examination of the weld seams of 304, 321 and 316Ti steels are given in Figure 5. As seen in the figure, no pores, cracks, slag residues or other welding defects were observed in the weld seams. The melting and penetration occurred during the welding process were sufficient and possible discontinuities were not encountered.

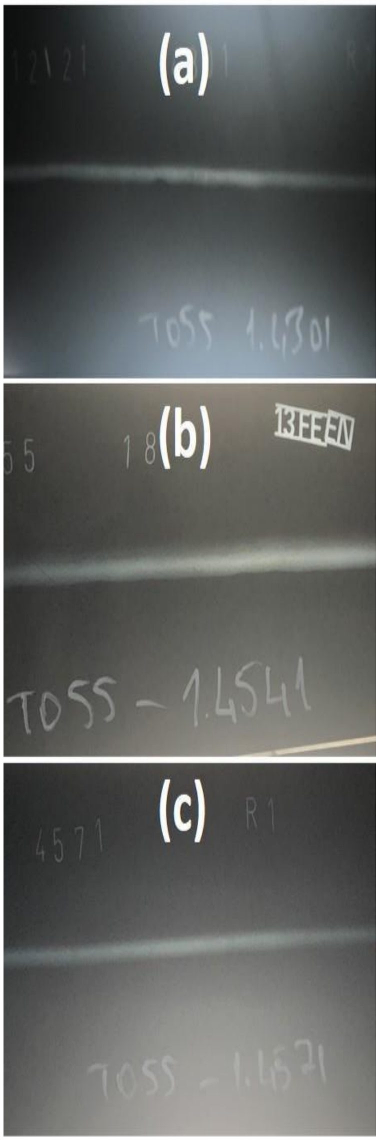


Figure 5. Radiographic inspection of seam welds of stainless steels: (a) 304, (b) 321 ve (c) 316Ti

Microstructure examinations of weld metal, heat affected zone (ITAB) and base material of welded 304, 321 and 316TI materials were made under SEM and the images are given in Figures 5, 6 and 7. As can be seen from the figures, it is seen that all three areas have different microstructures. When looking at the microstructure in the weld metal region, a coaxial and homogeneous structure is seen. A coarsening is observed in the grains due to the heat input in the HAZ (heat affected zone) area [8] When the SEM images of the unaffected base metal are examined, the grains found here are smaller in size and have homogeneous dimensions.

Controlling the cooling with a ceramic underlay during welding prevented excessively rapid cooling.

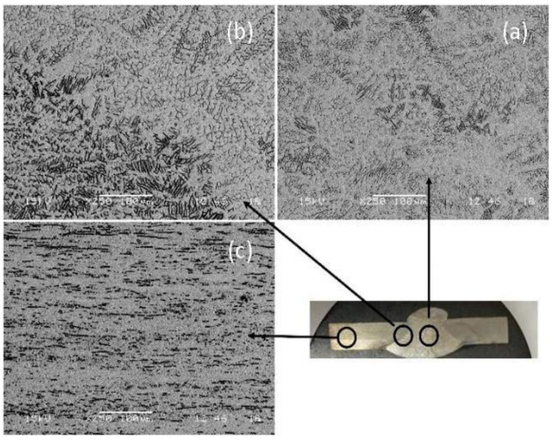


Figure 6. 304 stainles steel (a) Molten zone (b) HAZ (c) Base metal which is unaffected by heat.

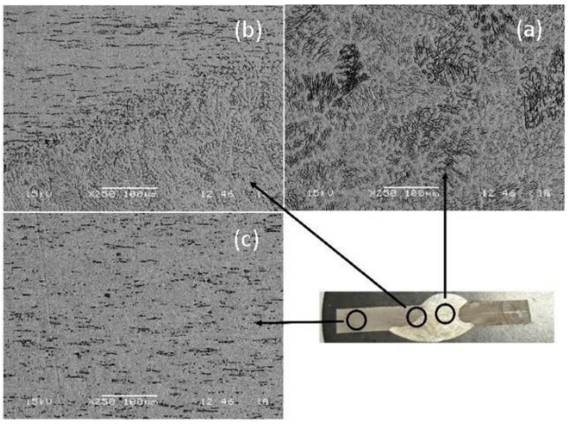
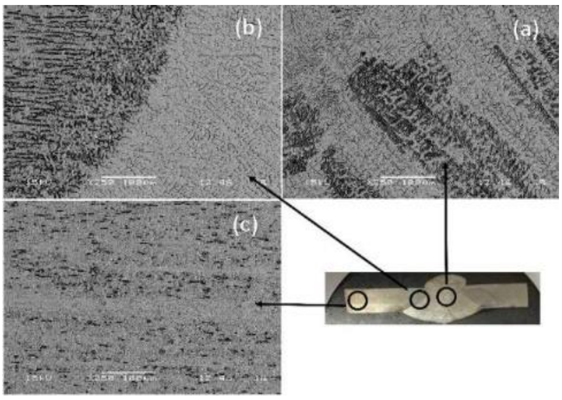


Figure 7. 321 stainless steel (a) Molten zone (b) Haz (c) Base Metal which is unaffected by heat.



Row hardnesses o *Figure 8. 316Ti Stainless Steel (a) Molten zone (b) HAZ (c) Base Metal which is unaffected by heat*

f the welded materials are taken as shown in Figure 3 and the values are given in Table 3. In 304, 321 and 316Ti steels, the weld metal area is the stiffest area. The hardness of the weld metal 316LSi was between 210-240 HV, these values are compatible with the literature. [9] The lowest hardnesses were measured in the HAZ(heat affected zone) areas of all three materials. It is known that the heat input and the grain coarsening caused by this heat input cause a serious decrease in hardness in the HAZ area. [9]

Table 3. Row hardness of welded materials

	Zonal hardnesses (Vickers, HV)						
	-3	-2	-1	0	1	2	3
304	247	214	211	206	146	194	202
321	212	215	231	178	191	180	207
316Ti	214	213	198	213	174	185	191

The tensile test results of 304,321 and 316Ti quality steels in their unwelded condition are given in Figure 9. The yield and tensile strength of 304 quality steel was the highest. The yield strengths of 321 and 316Ti quality steels are very close to each other, while the tensile strength is higher than that of 321 quality. Looking at the elongation percentages, 304 grade has the highest elongation value with approximately 50% elongation. The elongation values of 321 and 316Ti grades are very close to each other. When the yield, tensile strength and percent elongation values of all three grades of steel are compared with other studies, the results are compatible. [10]

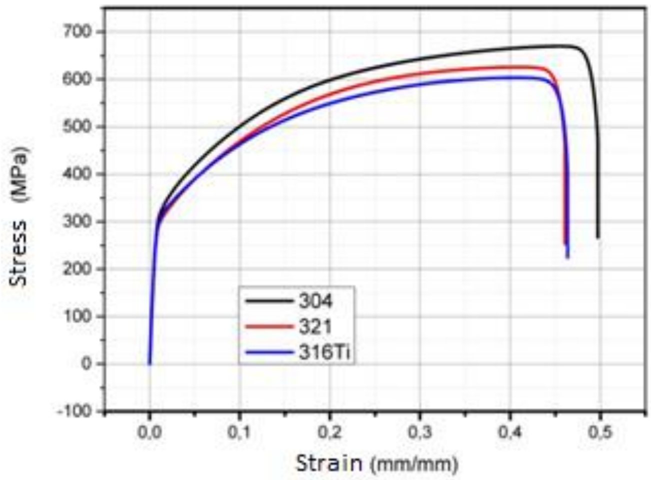


Figure 9. Tensile test results of 304, 321 and 316Ti steels in unwelded condition.

Three different grades of steel were welded with 316LSi and their tensile tests were carried out. The stress-strain plot of all three steels is given in Figure 10. Welded 304 quality steel has the highest yield and tensile stress values. The tensile strength of 321 grade steel was higher than 316Ti grade steel, but the elongation percentage of 316Ti grade steel was higher.

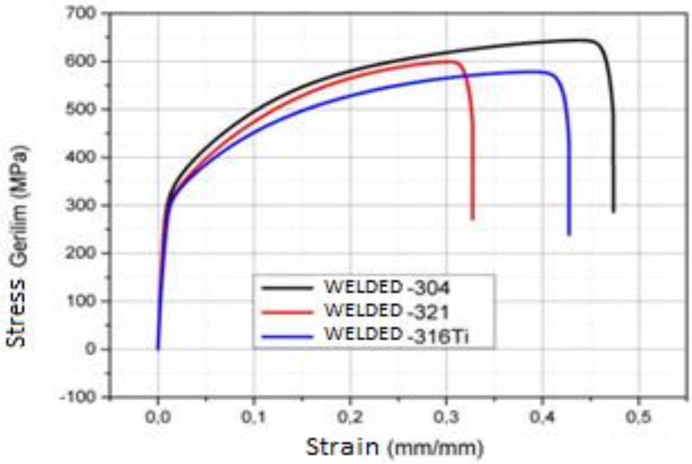


Figure 10. Tensile test results of welded steels 304, 321 and 316Ti.

Tensile test results of welded and non-welded materials are given in Figure 11. The graph shown in Figure 11 was formed by taking the average of 3 different test samples made for the sample types. According to the results obtained from the tensile test, it is observed that the welded samples reach lower stress values and lower elongation values.

Looking at the table, it was observed that the welded samples snapped earlier. The reason why the yield and tensile strengths of welded samples are lower is the grain coarsening in the HAZ(heat affected zone) area. [8] Grain coarsening in the HAZ area diminished both strength and ductility. In the tensile tests of welded samples, the rupture occurred in the HAZ area, not in the weld area. 304 quality steel has the highest tensile strength values, both welded and unwelded. The tensile strength and elongation values obtained after the tensile test of welded and unwelded samples are given in Table 4.

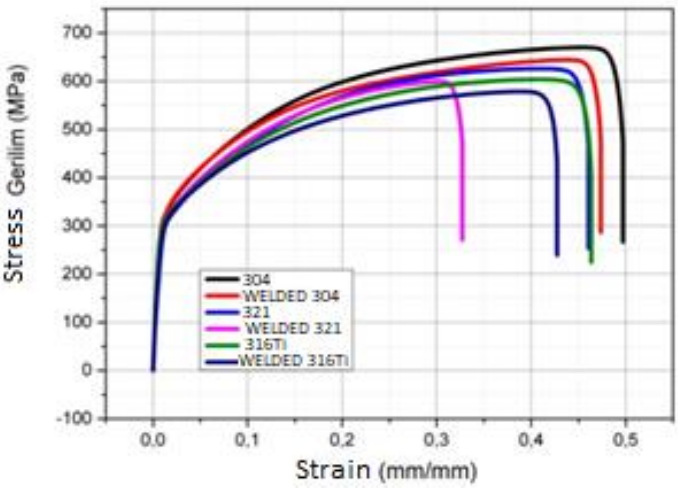


Figure 11. Tensile results of welded and unwelded states of the 304,321 and 316Ti steels.

Table 4. Values obtained after tensile test of welded and unwelded samples.

Material	Tensile strength (Mpa)	Elongation % (mm/mm)
304	669	0,49
304-Welded	643	0,47
321	625	0,46
321-Welded	599	0,32
316Ti	603	0,46
316Ti-Welded	577	0,42

4. Conclusions and Recommendations

In this study, the mechanical and metallurgical properties of both welded and unwelded forms of 304, 321 and 316Ti steels were investigated. Obtained results are given below.

All three materials were welded with 316LSi and radiographic examination of the weld seam was performed. No discontinuity was found as a result of radiographic examination.

The weld zone, the HAZ area and the microstructure of the base material were investigated by SEM. Grain coarsening in the HAZ area was visualized by SEM.

Tensile tests were carried out on different qualities of steels. 304 quality steel has the highest tensile and strength values, both welded and unwelded. 316Ti quality steel has the lowest tensile strength values. Tensile strength and elongation percentage decreased in materials after welding process.

5. Acknowledge

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