Effect of welding methods for different carbon content of ss304 and ss304l materials on the mechanical properties and microstructure

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Abstract. Austenitic stainless steel types of SS304 and SS304L are most widely used in the industrial manufacturing because it has excellent weldability and corrosion resistance. It is undeniable that welding is one of the common steps in the manufacturing process and repairing damaged equipment. In this study, three different welding methods including TIG (Tungsten Inert Gas), SMAW (Shielded Metal Arc Welding), and MIG (Metal Inert Gas) are described to compare mechanical properties and morphological analysis. The characterizations were conducted by tensile test, XRD, and Metallography. The results of this study indicate that MIG causes higher tensile strength compared to TIG and SMAW, the highest tensile stress value occurs in SS304 material with MIG welding of 679.64 MPa, while the lowest tensile stress value in SS304L material with SMAW welding of 604.89 MPa. Based on microstructure analysis, Both materials present austenite, ferrite, and Cr carbide phases.

1. Introduction
Stainless steel is an alloy steel with high alloy content (high alloy steel) and has suitable properties for corrosion and high-temperature resistance. Corrosion-resistant properties are caused by the stable oxide layer (especially Chrome) that adheres to the surface and protects the steel against a corrosive environment. Stainless steels are commonly used for the manufacture of vacuum tubes, plasma storage components, supporting structures, and various other subsystems [1]. SS304 alloy steel is a type of stainless steel austenitic stainless steel that composition of 0.042% C, 1.19% Mn, 0.034% P, 0.006% S, 0.58% Si, 18.24% Cr, 8.49% Ni, and the rest Fe. Some mechanical properties owned by type SS304 stainless steel include tensile strength of 646 MPa, yield strength of 270 MPa, 50% elongation, hardness of 82 HRB.

SS304L is used as a defense material and nuclear field because of its corrosion resistance in the excellent seawater environment. Such properties are due to having molybdenum content to prevent corrosion due to the element chloride. Besides, low carbon content can increase the resistance to grain boundary corrosion (intergranular corrosion) [2]. SS304L alloy steel is a type of stainless steel austenitic stainless steel which has a composition of 0.027% C, 0.39% Si, 1.61% Mn, 0.025% P, 0.011% S, 8.01% Ni, 18.27% Cr, 69.24% Fe. The low carbon content of 0.03 wt% in SS 304L causes a small amount of carbide precipitation to form. Therefore, SS304L is suitable for welding and used as a power plant application [3]. The chemical composition of SS304 and SS304L alloys is the same except the carbon
content. SS304 has a higher carbon content of 0.8% due to high carbides content. It is also applied as pressure vessel reactor materials [4].

SS application for industrial equipment cannot be separated from the welding process. Welding is an attempt to connect the material both the same material and different materials using heat energy and affect both mechanical properties, metallurgical structure, deformation, and thermal stress. Welding techniques need to be considered because they affect the mechanical properties of the material and the performance of the equipment produced. When welding occurs, there are several problems involving changes in stress on the materials caused by changes in the microstructure in the area around the weld. Such a phenomenon will result in a decrease in material strength due to residual stress and making cracking easier [5].

The two types of austenitic SS304 and SS304L are used as power plant materials, one of which is a pressure vessel. In the power plant, there are reactor pressure vessels and SS pipes. Therefore, the welding process should be carried out. In this type of SS welding, many failures occur in the heat-affected zone (HAZ) and the welded zones [6]. Some failure factors for SS welding need to be known both in terms of welding implementation and base metals. Based on previous research, mechanical properties and microstructure analyzes have been carried out separately for welding SS304 or SS304L material (7,8,9,10). Both materials have different compositions in carbon content. Therefore, this study will compare the mechanical properties of SS304 and 304L materials. This research aims to analyze the effect of carbon levels of SS304 and SS304L which are carried out by various of welding methods on mechanical properties and microstructure analysis.

2. Experimental Method
The experimental procedures of this research are divided into three processes such as specimen preparation, welding process, and characterization. In the specimen preparation process, the materials used in this study are SS304 and SS304L. Both materials were prepared by cutting and making V groove for 60° of groove angle. Furthermore, welding is carried out using several types of welding which are TIG, MIG, and SMAW with a current of 100 amperes and voltage of 220 volts. The protective gas used in TIG, MIG welding is argon 99.9%. The fillers of TIG and MIG are ER308L in diameter of 1.6, and the SMAW uses electrodes of type E308-16 in diameter of 2.6. Welded materials were characterized by tensile test, metallography, and X-Ray Diffractometer (XRD). Tensile test is carried out to determine the tensile strength, yield strength, and elongation materials. The schematic of tensile test specimens was shown by Figure 1. Macro observation determined the three zones in welding: The Heat Affected Zone (HAZ), the base metal, and the weld metal area. The sample surface was grinded using SiC paper from grade 200 to 2000 and polished by alumina powder. The etched surface should be smooth and continued by etching process to clarify the grain boundary. An optical microscope was used to show the microstructures of samples and XRD analysis determined the phases formed after the welding process. XRD analysis is carried out from a diffraction angle of 20-100°.

![Figure 1. Schematic of welded samples for tensile test [11]](image)

3. Results and Discussion
Figure 2 shows the yield strength of welded SS304 and SS304L material using various welding methods. The highest yield strength of SS304 material in MIG has a yield strength of 523.3 MPa. The lowest yield strength of SS304 materials under SMAW method has a yield strength of 468.02 MPa. In SS304L materials, the highest yield strength of TIG is 445.66 MPa. The lowest yield strength of MIG welding
SS304L material is 432.3 MPa. The yield value of SS304 materials is higher than SS304L caused by the SS304 materials increases the yield strength of filler metal. Otherwise, the yield strength of SS304L material is lower than SS304 due to the yield strength of filler metal decreases after welding process.

![Figure 2. Yield Strength of materials using variations of welding methods](image)

Based on Figure 3, the highest tensile stress value occurs in SS304 material with MIG welding because the mechanical strength of ER308L as a filler metal have increased in MIG welding method. The tensile strength of ER308L filler is 550 MPa and increases for 19.07% to 679.64 MPa after welded. The lowest tensile stress value on welded 304L belongs to SMAW welding. Tensile stress values in SS304L material are slightly different between SMAW, TIG, and MIG welding. Otherwise, SS304 materials using TIG and MIG welding have a significant difference in tensile stress elucidating that welding methods affects the tensile strength of materials. The fracture area of the tensile test specimen for SS304 occurs on the weld metal.

![Figure 3. Tensile Strength of materials using variations of welding methods](image)

The tensile strength of SS304 material showed the highest tensile strength results for all welding methods because SS304 has Si element content while SS304L has less Si element content. Si element metal in metals has the role of improving the tensile strength of the materials [12]. The lowest tensile strength value of the test sample occurs when the SMAW welding method is used due to the mechanical strength of filler materials decreases after the SMAW welding with E308-16 electrodes.
The elongations properties of SS304 and SS304L welded using different methods were shown in Figure 4. SS304L material has inversely proportional between yield strength and elongations. SMAW has the lowest tensile strength, while elongation has the highest value of 33.52%, compared to TIG welding of 32.66% and at MIG of 30.92%. Welded SS304 material in SMAW method has the lowest elongation value of 23.63 % followed by TIG and MIG of 23.74% and 27.15%, respectively. The highest elongation value at SS 304 welded joints occurs in MIG welding that has an elongation of 27.15%.

Macrostructure analysis confirms three zone of welded materials including base metal, HAZ, and welded metal. This analysis was conducted by ASTM E08. Figure 5 presents the macro image of SS304L material with TIG, MIG, and SMAW welding methods. HAZ zone of SS304 appears clearly and is shown by white spot but HAZ of SS304L is not visible. Low carbon content of SS304L causes a narrow area of HAZ [13]. The weld metal distribution on the 304L SS welding by the TIG method was slightly widened and also in MIG welding. SS304L welded by SMAW method shows clearly in V groove shape.

Figure 4. Elongations of materials using variations of welding methods

Figure 5. Macro structures for (a) SMAW (b) TIG (c) MIG for SS304 and (d), (e), (f) for SS304L, respectively
Regarding macrostructure images, further observations was conducted by microstructure analysis under optical microscope. Based on Figure 6, it can confirm the difference between three welding zones that have significant difference of grain structure. The morphological structure of HAZ describes the boundary of base metal and weld metal zone. It has grain structure among other zones because of the rapid cooling in the base metal. Therefore, HAZ has the highest hardness value. There are visible phases on microstructure images which consist of austenite, martensite, and Cr (chromium) carbide with fine granules (black spots) [14]. The weld and HAZ regions for specimens with TIG welding produce the most delicate grain structures dominated by austenite dendrite structures [15]. Moreover, the microstructure of the welding area and the HAZ of MIG welding produce a grain structure. The large austenitic grains using SMAW welding can be ascertained the strength and toughness from the tensile test. The mechanical properties of SMAW welding are the lowest value that other various welding methods.

![Figure 6](image)

**Figure 6.** Microstructures for SS304 (a) SMAW (b) TIG (c) MIG

![Figure 7](image)

**Figure 7.** XRD patterns of SS304 materials using variations of welding methods
XRD analysis used to analyze the phases contained in material SS304 and SS304L after welding with different methods shown by Figure 7 and figure 8. XRD is tested at the angle range of 20-100°. Both SS304 and SS304L materials have a similar XRD pattern and the samples have a predominant phase in the form of austenite and martensite [16]. The presence of austenite is more than martensite phase in both SS304 and SS304L materials because SS304 materials have more austenite phase than other types of stainless. Cr carbide and ferrite cannot be identified by XRD pattern because of low amount phases [17]. A clear difference in this XRD analysis is that the SMAW welding carried out on both SS304 and SS304L samples has a different peak position 2θ of 44.5°. This angle shows the peak austenite that is not owned by samples welded using TIG and MIG. The existence of this peak causes the low mechanical properties of the material welded using the SMAW method for both SS304 and SS304L.

4. Conclusions
Based on those data observations, it can be concluded that the TIG, MIG, and SMAW welding techniques affect each material, including the results of the tensile test, microstructure test, and macro. SS304 welded by MIG method has the highest tensile strength of 679.64 MPa. Otherwise, the SS304L material has the highest tensile strength of 617.32 MPa resulting from MIG welds. It can be concluded that MIG method affects the highest strength of both materials. In the macro photo test, there is a difference in HAZ width caused by elemental content of stainless steel. Moreover, there are obvious phases are austenite, Ferrite, and Cr (chrome) carbides on SS304 using various welding methods. It is confirmed by XRD pattern which austenite exists in SS304 and SS304L materials.

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