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Effect of Welding Current on Joining of AISI 316 L Steel by TIG Welding Process

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Abstract

AISI 316L is one of the most widely used austenitic stainless-steel types today. Since it has less carbon content than AISI 316, annealing is not required even in thick sections, especially after welding processes. In this study, 6 pieces AISI 316L plate in 220x70x10 mm were combined by TIG welding method with different welding currents, keeping the conditions the same, and their differences were tried to be revealed experimentally. Micro and macro structural properties, changes in hardness, fracture energies, three-point bending tests and tensile tests of the samples of which welding processes were completed were carried out according to current standards and the results were compared with each other. As a result of the experiments and analyses, it has been determined that the change in the welding current value affects the mechanical properties of the welded joint when joining AISI 316 L austenitic stainless steel with TIG welding method and the most appropriate value for this study is 150 A.

Keywords: AISI 316 L; TIG; Welding current; Experimental; Microstructure; Mechanical properties.

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1. INTRODUCTION

Stainless steel is the general name given to steels that do not rust in oxidizing environments, and they contain at least 10-12 wt.% Cr and up to 1.2 wt.% C in their chemical composition. Compared to unalloyed and/or low-alloy steels, it is one of the indispensable materials of today's industry in terms of corrosion resistance and is widely used in many areas of industry. In addition to their superior corrosion resistance, stainless steels also have advantageous features such as advanced mechanical properties, ability to be used in a wide temperature range, easy shaping and aesthetic appearance [1,2].

The excellent corrosion resistance of stainless steels is due to their high chromium content. When they encounter an oxygenated environment, a protective chromium oxide layer forms on the surface due to the Cr in their structure, thus preventing corrosion [3,4]. Stainless steels, in terms of their microstructure; they are classified as austenitic, ferritic, martensitic, duplex, and precipitation hardened stainless steels [5].

One of the most used types of austenitic stainless steels is AISI 316 (X5CrNiMo17-12-2). This austenitic stainless steel also has varieties such as AISI 316 L, AISI 316 H and AISI 316 Ti. To briefly summarize the features of these

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varieties, AISI 316 L contains less carbon than AISI 316, while AISI 316 H contains more carbon. AISI 316 Ti differs because it contains titanium. These differences not only affect the mechanical properties, but also create differences during and after welding operations. To summarize, in productions where AISI 316 type stainless steel will be used, AISI 316 L should be preferred if joining by welding is involved, if the material will work at high temperatures, AISI 316 Ti should be preferred, and if there is a possibility of intergranular corrosion, AISI 316 H should be preferred. [6,7].

Most stainless steels have high weldability and can be welded by different methods such as arc welding, electron welding, laser welding, friction welding, resistance welding or brazing. The corrosion resistance of austenitic stainless steels is higher than martensitic and ferritic stainless steels. For this reason, welding of this type, which is widely preferred among stainless steels, is very important [8]. There are several important factors affecting the weldability of austenitic stainless steels [9]. Three main welding problems are encountered when welding austenitic stainless steels. The first of these is the sensitive structure formed by the formation of "Chromium Carbide" in the heat affected zone (HAZ), the other is the "Hot Crack" observed in the weld seam, and the last is the risk of "Sigma Phase" formation seen at high operating temperatures [10].

Although the welding methods listed above are used in welding stainless steel, the most used method is TIG (Tungsten Inert Gas) welding, which is a gas welding method with a non-melting electrode and is in the arc welding group. In TIG application, an arc is created between the tungsten electrode and the workpiece, protected by an atmosphere of argon or helium gas. Additionally, filler metal (welding wire or rod) is required [11]. Although the TIG welding method can be applied to parts of all thicknesses and positions, it is not preferred when joining steel parts thicker than 7 mm due to the long process time and high cost. On the contrary, it is also preferred in joining very thin materials [12,13]. Figure 1 below shows the TIG welding method schematically.

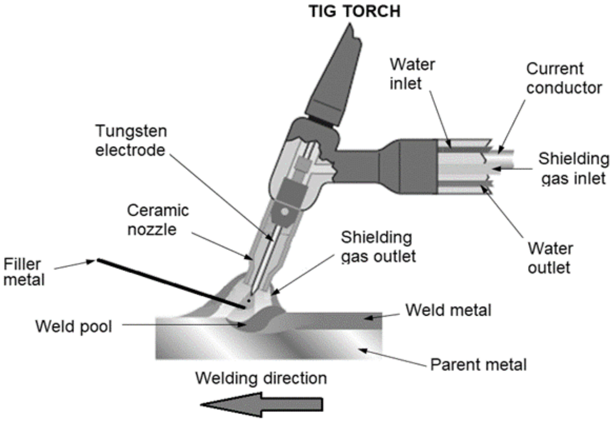

Figure 1. Principle of TIG Welding [14].

Since TIG welding is the most common method for welding stainless steel materials, as explained above, if a stainless steel material thicker than 7 mm is to be welded; in order to prevent chromium carbide precipitation at grain boundaries and therefore corrosion resistance to decrease, either heat treatment should be applied after the material is welded or series with carbon content lower than 0.03% (for example, using AISI 316 L instead of AISI 316) should be used.

The tungsten electrode placed in the torch used in TIG welding, unlike the electrodes used in other arc welding methods, is not used for filling purposes, but for thermal conduction, and therefore it is not depleted. The melting required for welding is achieved thanks to the high heat produced by the electrons released due to the electric current given to the tungsten electrode. In TIG welding, filler metal may also be used. Filler metals are welding wires manufactured in accordance with international standards and used to create a weld pool by melting with the main material during welding.

There are many studies on joining stainless steel types with TIG welding method. Many parameters and material properties vary in these studies. In this study, it is aimed to join 316 L material, which can be considered especially thick, by using different welding currents. Thus, it was tried to reveal how the welding current affects the mechanical properties of the welded joint and which of the selected current values would be appropriate.

2. EXPERIMENTAL

In this study, AISI 316 L plates with dimensions of 220 x 70 x 10 mm were joined by TIG welding method using different current intensities, and then microstructure examinations, macrostructure examinations, hardness measurements, bending tests, tensile tests and notch impact tests of the samples prepared from the welded plates were carried out. The chemical compositions of the certified AISI 316 L plates used in the experiments are listed in Table 1 below.

Table 1. Chemical composition of AISI 316 L.

Elements	C	Si	Mn	P	Cr	Ni	Mo	N
wt.%	0.016	0.46	1.13	0.03	16.6	10.0	2.1	0.04

In welding processes where other parameters were the same, joints were made with three different welding currents: 150 A - 175 A and 200 A. For welding operations performed in the form of butt weld joints, the joints were completed with a total of three passes, by the help of Argon, which was used as a protective gas, after the welding mouth was opened. Welding rods complying with the ER316L standard were used for welding operations. Parameters used in welding processes performed with an average travel speed of 250 mm.min.$^{-1}$ are given in Table 2 below.

Table 2. Welding parameters without current value.

Welding Current	**Shielding gas**	**Gas Flow Rate**
DC (Direct current)	Argon	15 l.min^{-1}
Electrode Type / Diameter	**Filler Wire Diameter**	**Torch Cup Diameter**
Tungsten / 3.2 mm	3.2 mm	8 mm (size 5)

The most important parameters for the TIG Welding method are current type, tungsten electrode condition, shielding gas flow rate, current intensity, polarization type, arc voltage and welding speed. In this study, welding operations were carried out by an expert TIG welder, taking these parameters into consideration and with the contribution of research in the literature. An example application of welded joints is shown in Figure 2 below.

Figure 2. Application of the welding process to plates.

From each of the plates of which welding processes have been completed, 2 tensile test samples, 4 bending samples (two for root bending and two for face bending), 6 Charpy notch samples (three from the HAZ and three from the welding area) have been prepared. Additionally, one sample from each plate was prepared for microstructure, macrostructure and hardness measurements. All mechanical tests of welded samples were carried out by TEKNOLAB inspection company, which has EN ISO 17025 accreditation. The schematic representation showing how the test samples prepared in accordance with the standards are taken from welded plates is included in Figure 3 below.

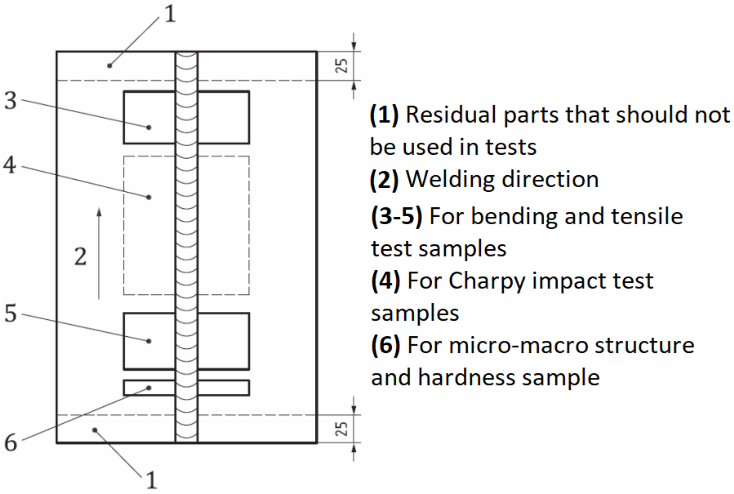

Figure 3. The schematic representation of the test samples prepared from welded plates.

2.1 Metallographic Examinations

For metallographic examinations, a sample taken from each plate was subjected to microscopic study according to EN ISO 4499 [15]. For micro and macro structure examinations, each of the samples was sanded with 80 to 1200 grit emery paper. The samples, of which grinding process was completed, were then polished with the help of 1 µm particle sized diamond paste and finally etched with royal water (3:4 HCl + 1:4 HNO_3). After sanding, polishing and etching processes were applied to the samples respectively, their microstructures were examined under the optical microscope and integrated digital camera. Microstructure images of the samples are shown in Figures 4, 5, and 6 below respectively.

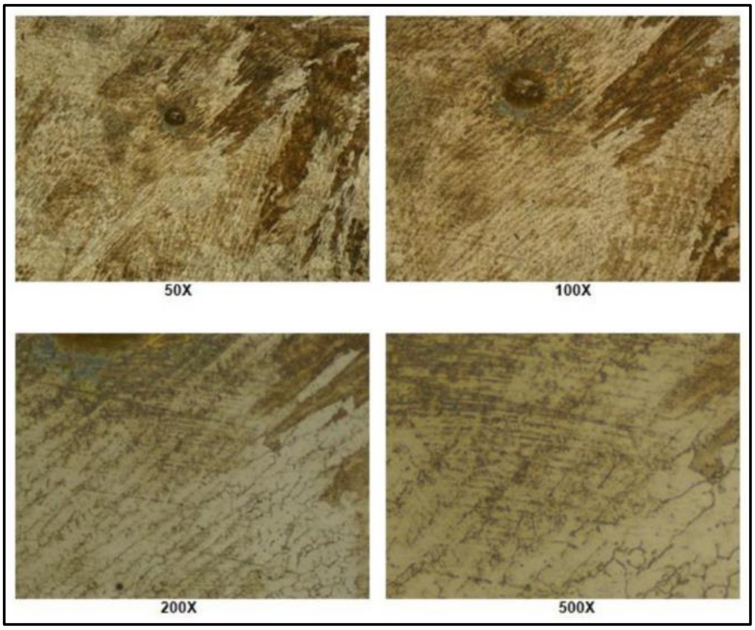

Figure 4. HAZ and weld microstructure of the plate welded with 150 A current.

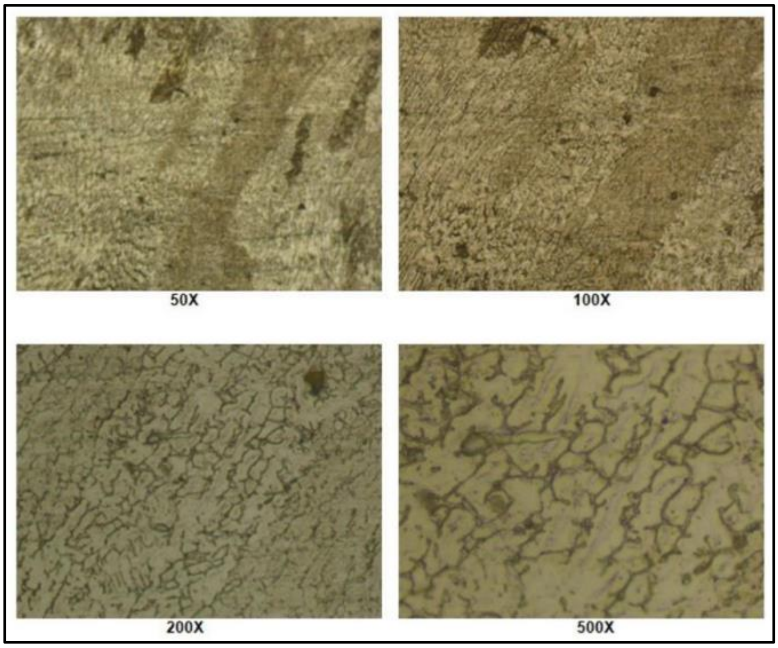

Figure 5. HAZ and weld microstructure of the plate welded with 175 A current.

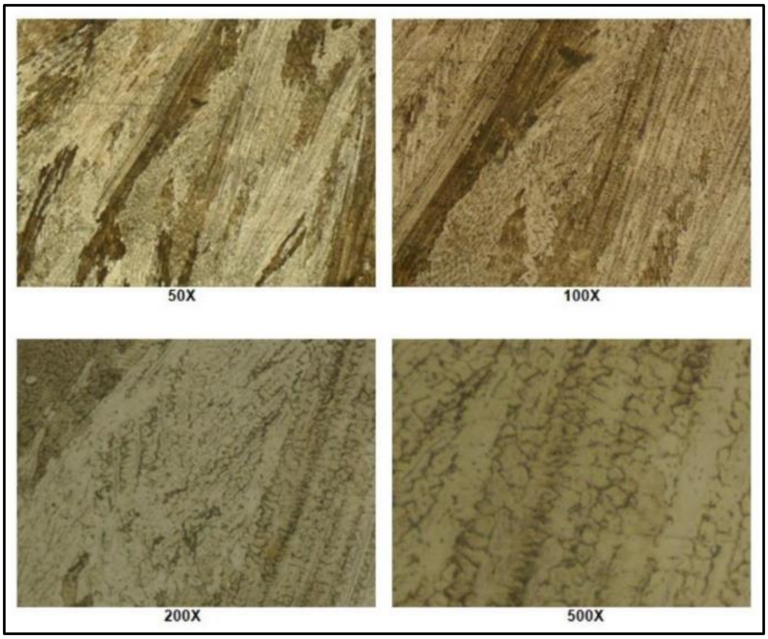

Figure 6. HAZ and weld microstructure of the plate welded with 200 A current.

After the microstructure examinations, the images of the macrostructural examinations carried out in accordance with the EN ISO 17639 standard [16] are shown below in Figure 7, 8, and 9, respectively.

Figure 7. Macrostructure of the plate welded with 150 A.

Figure 8. Macrostructure of the plate welded with 175 A.

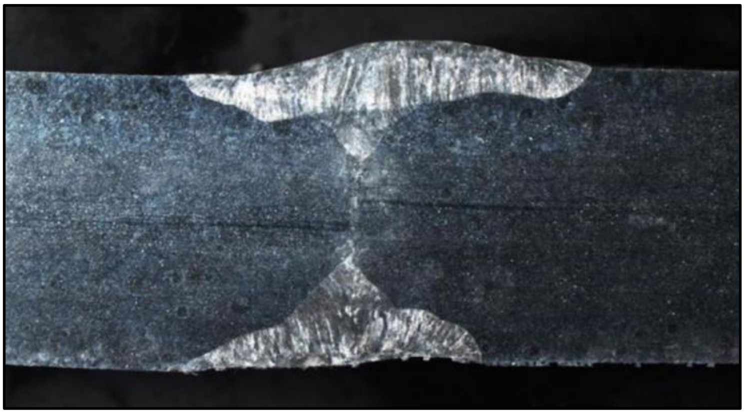

Figure 9. Macrostructure of the plate welded with 200 A.

2.2 Hardness Examinations

Hardness measurements of the samples were carried out according to EN ISO 9015-1 standard [17] with the help of a Vickers hardness device, applying a load of 10 kg. Hardness measurement results are shown below in Figures 10, 11 and 12, respectively

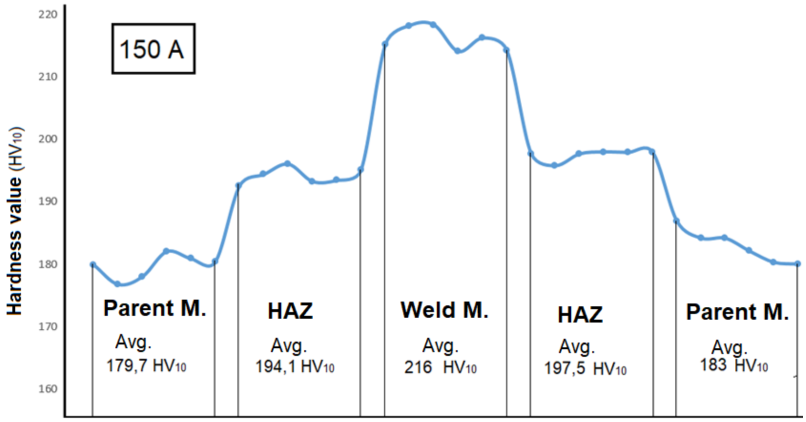

Figure 10. Hardness measurements of the plate welded with 150 A.

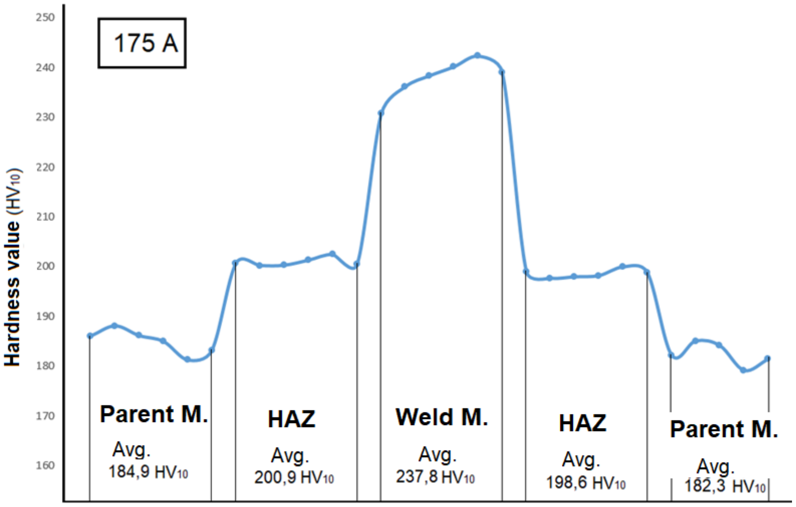

Figure 11. Hardness measurements of the plate welded with 175 A.

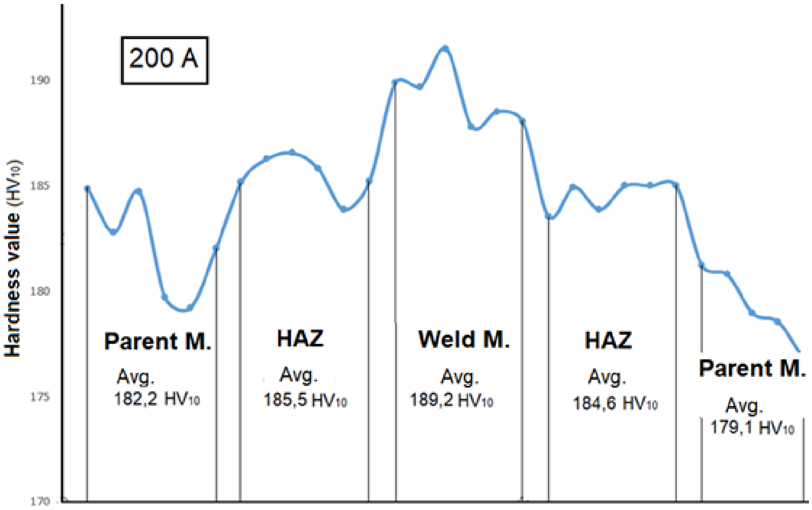

Figure 12. Hardness measurements of the plate welded with 200 A.

2.3 Tensile Tests

For tensile tests carried out in accordance with EN ISO 4136 standard [18], two samples were prepared for each current value. Tensile test results of the samples are given in Table 3 and the stress-strain graphs of the one of each samples are given in Figure 13 below.

Table 3. Tensile test results of the samples.

Welding current (A)	Tensile Strength (MPa)	Breaking Zone
150	388±13	Weld M.
175	397±13	Weld M.
200	381±24	Weld M.

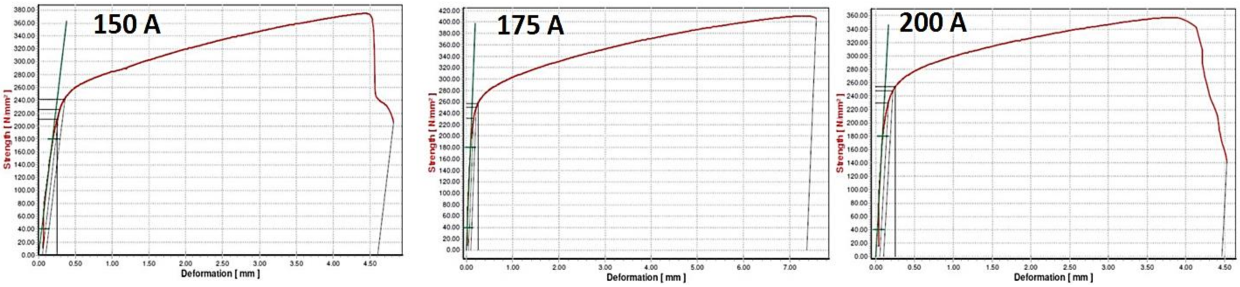

Figure 13. The stress-strain graphs of the welded samples.

2.4 Bending Tests

For the bending tests carried out in accordance with EN ISO 5173 [19], 2 face and 2 root bending samples were prepared from each plate. Bending test results of the samples are given in Table 4 below.

Table 4. Bending test results of the samples.

Welding current (A)	Weld seam direction	Sample	Bending angle	Results
150	Face	1	180°	Undamaged
		2		Undamaged
	Root	1		Undamaged
		2		Undamaged
175	Face	1		Undamaged
		2		Undamaged
	Root	1		Undamaged
		2		Undamaged
200	Face	1		Damaged
		2		Damaged
	Root	1		Undamaged
		2		Undamaged

2.5 Charpy Impact Tests

In terms of mechanical tests, lastly Charpy Impact tests were carried out. According to the EN ISO 9016 standard [20], three samples were tested separately from the HAZ and weld seams of each plate, and the fracture energies were determined separately by taking the average of each region. Charpy test results are given in Table 5 below.

Table 5. Charpy test results of the samples.

Welding current (A)	Notch area	Test 1 (J)	Test 2 (J)	Test 3 (J)	Average Fracture Energy (J)
150	HAZ	265.12	255.96	240.99	254.02
	Weld M.	235.87	236.9	240.26	237.68
175	HAZ	76.35	71.38	69.31	72.35
	Weld M.	49.3	47.4	50.53	49.08
200	HAZ	53.2	50.17	58.9	54.09
	Weld M.	46.85	50.88	41.09	46.27

3. RESULTS AND DISCUSSION

In this study, the effect of changes in the welding current value on the mechanical properties of the AISI 316 L material welded with TIG welding method was tried to be examined and the most appropriate welding current value was determined. As a result of the tests carried out in accordance with EN ISO standards, differences in mechanical properties occurred as the welding current value changed.

When the microstructure images were examined, it was determined that the weld zone of the AISI 316 L material welded with a current intensity of 150 A consisted of austenite as well as grain boundary ferrite and sigma phase. It was determined that the AISI 316 L material welded with 175 A current intensity had a smaller grained austenite structure compared to the weld zone of the material welded with 150 A current intensity, as well as ferrite and partial sigma phase at the grain boundaries. Finally, it was determined that the welding area of the AISI 316 L material, which was welded with a current intensity of 200 A, generally consisted of austenite, but structurally it had very fine grained and oriented austenite grains and a small amount of grain boundary ferrite formation. The phase images of the samples are shown in Figure 14 below.

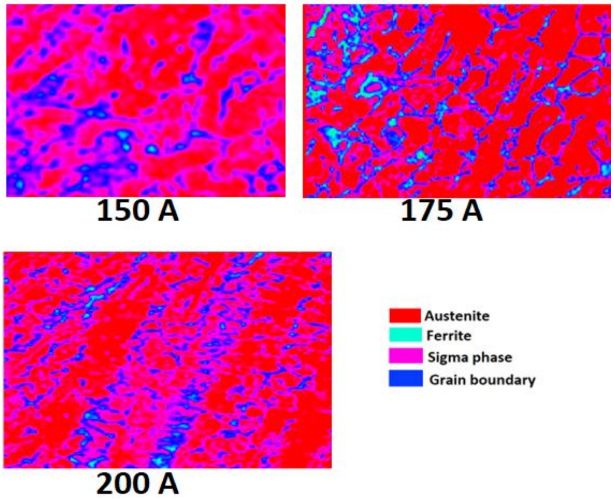

Figure 14. Phase images of the weld metal microstructures.

In a different study, it is seen that the microstructure of AISI 316 L, which was joined by TIG welding method with 80, 90, 100 and 120 A current intensities and 15 l/min gas flow rate, is like this study [21]. As a result of the macrostructure examinations, it was determined that the surface weld of the AISI 316 L material, welded with a current intensity of 150 A, penetrated approximately 5 mm into the material and the root weld penetrated approximately 3 mm into the material and there was no visual adverse effect. In the macro structure of the AISI 316 L material welded with a current intensity of 175 A, it was determined that the surface and root welds penetrated approximately 3 mm into the part and there was no visual adverse effect. In the macro structure of the AISI 316 L material welded with a current intensity of 200 A, it was determined that the surface and root welds penetrated approximately 3 mm into the material, but when examined in detail, some regions between the plates had joining errors.

When the bending test results were examined according to EN ISO 5173, no damage occurred in the samples welded with 150 A, and 175 A current intensity, while the face bending results of the samples welded with 200 A current intensity resulted in separation from the root zone. It is thought that this situation may be due to lack of penetration or joining errors, which were also determined in macro examinations.

When the Charpy test results were examined, it was determined that as the welding current value increased, the impact energies decreased in both the HAZ and welding regions. In addition, the highest values in terms of fracture energies were reached in samples welded with a current intensity of 150 A. Although this is usually due to microstructural changes, other factors such as the penetration depth of the weld, sigma phase content, internal defects, etc. is also possible that it may arise from certain circumstances.

Although it was determined that there was an increase in hardness measurement values from the main material to the weld metal for all samples. It can be said that this increase is due to the partial reduction in the austenite size in the HAZ and the presence of the sigma phase in the weld zone. With this the most stable values were obtained in the welded sample at 150 A current value. In a similar study, it was stated that the hardness values of 20 mm thick AISI 316 L, joined by TIG welding method with 220 A current intensity and 15 l/min gas flow rate, decreased from the weld metal to the base metal [22].

When the tensile test results were examined according to EN ISO 4136, it was determined that all three samples break from the weld metal and tensile strengths were close to each other. This is due to microstructural properties that have changed due to high current and partly to penetration problems. In another study, 2 mm thick AISI 316 L was joined by TIG welding using different welding parameters, and it was stated that the tensile test samples broke off from the weld seam, and that no problems were found in the bending samples [23].

As a result, it has been determined that the welding current value affects the mechanical properties when joining AISI 316 L austenitic stainless steel with TIG welding, and the most optimum value among the welding current values applied in this study was determined to be 150 A. In a study carried out to determine the optimum TIG welding parameters of 3 mm thick AISI 316 L, mathematical modeling was also carried out and because of the welding processes performed between 100 A and 150 A current intensities, the most suitable values in terms of mechanical properties were 129.3 A and 8.91 flow rate has been determined [24]. This result shows that a current value above 150 A is not suitable for joining AISI 316 L with TIG welding, as revealed in this study.

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*In the contribution section, indicate the number(s) that correspond to the relevant contribution type.			
1- Study design 2- Data collection 3- Data analysis and interpretation 4- Manuscript writing 5- Critical revision			

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