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Investigation of Post-weld Heat Treatment of Laser Welded Ti6Al4V Materials

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Abstract
In this study, the changes in the internal structure and mechanical properties of laser-welded Ti6Al4V material after the heat treatment process were experimentally investigated. The transformation temperatures of the α and β phase structures of the Ti6Al4V material influenced the heat treatment temperatures. Optical microscopes, XRD, and SEM experiments were performed to detect the microstructural change. Tensile and hardness tests were also carried out to determine the change in mechanical values. The experimental study determined that the mechanical values of laser-welded Ti6Al4V material improved after the heat treatment process. It was determined that ductility and strength increased significantly at heat treatment temperatures above the β phase temperature value. It was observed that the Widmanstatten morphology visible in the weld area increased the hardness.

1. Introduction

Titanium alloys are widely preferred in chemistry, aerospace, medicine, and other industries. This situation is due to the high resistance of titanium material to corrosion, high fracture toughness, low density, and high strength/weight ratio [1]. One of the most widely preferred titanium alloys is Ti6Al4V. Ti6Al4V has α and β phases in its structure. These phases are one of the main factors in the change of microstructure and mechanical properties [2]-[4].

Laser welding is superior to other welding techniques with its high welding speed, narrow weld seam, low heat input, small heat-affected zone, automation compatibility, successful welding of different materials, and joining of different thicknesses [5]. Kashaev et al. took the material Ti6Al4V and fused it with Nd: YAG laser beam welding at the T weld position. At the end of the study, they obtained similar results with the base material in terms of elongation and tensile strength [6]. Xu et al. detected a high amount of α' phase in laser-welded Ti6Al4V material due to the sudden cooling in the weld zone. In addition, they reported that dislocation clusters caused plastic deformation in the weld area [7]. Akman et al. reported that penetration decreases with increasing welding speed, and welding power is proportional to penetration [8]. In another study, Keskin determined that laser welding is efficient in titanium alloys and that the welded samples break from the base material in tensile tests [9]. Köse and Karaca applied heat treatment to Ti6Al4V material before and after welding. When the results were examined, it was determined that the ductility and toughness values of the aged samples increased, and the hardness and tensile strength of the unaged samples increased [10]. Köse and Karaca reported in another study that different heat inputs are also effective in changing the structure of the welded material. According to the material's microstructure joined with low heat input, it was determined that grain coarsening of the material joined with high heat input occurred in the weld metal, and the volumetric ratio of the primary α phase in the weld metal increased. It has been reported that the weld metal microstructure of the material,

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combined with low heat input, consists of basket weave or acicular α' and primary β phases at the grain boundaries [11].

Heat treatment after laser welding is preferred to improve the material's mechanical properties. However, when the literature is examined, no study has been found on how the heat treatment performed at the transformation temperatures of the α and β phases in the Ti6Al4V structure affects the mechanical properties of the welded joint. This study applied heat treatment to the laser-welded Ti6Al4V part at the transformation temperatures of the α and β phases in its structure. The effects of this on the microstructure evolution and mechanical properties are discussed. It is the part that gives the purpose of the study and its place among the previous studies. The aim of this study should be clearly stated in the last paragraph of the introduction.

2. Material and Method

Butt welding was performed with the help of a laser welding machine, the IPG YLR-6000 laser welding machine. The laser power is 3000 watts, the welding speed is 2000 mm/sec, and the protective argon gas amount is 30 lt/min. In order to determine the optimum parameters in the laser welding process, experiments were carried out with different parameters, and smooth weld seams and good penetration were observed in the welding process with the above parameters. The chemical composition of the Ti6Al4V material is given in Table 1. The welding area is protected against oxidation with argon gas in the laser welding process. After laser welding, the test pieces were taken to the heat treatment process. The classification of test pieces is given in Table 2.

1) Heat treatment at 800 °C, below the α transformation (Tα) temperature of 880 °C;

2) Heat treatment at 950 °C, between Tα and Tβ (β conversion temperature 990 °C);

3) Heat treatment at 1080 °C on Tβ.

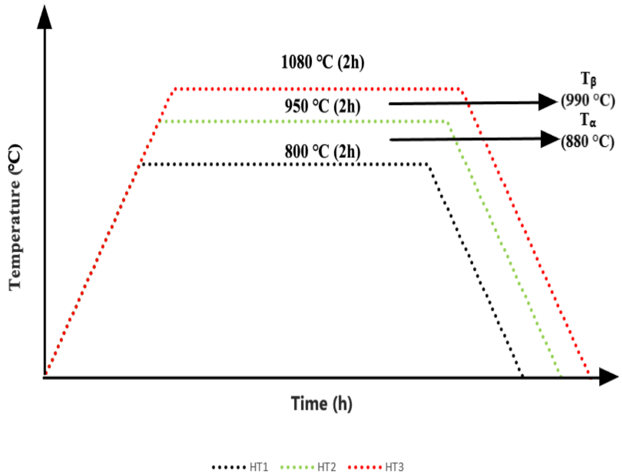

Figure 1. Heat treatment of laser welded Ti6Al4V materials.

Hardness, tensile and optical microscopy, SEM, and XRD tests were applied to the test specimens. Microhardness test was performed under 300 g load and 15 seconds load application parameters. The tensile test was performed in the form of uniaxial tension at room temperature and 0.5 mm/min speed in accordance with the ASTM E8/E8M-15a standard. Molded parts for the metallography experiment were sanded in the range of 200-2500 mesh, respectively. Then the pieces were polished on felt with the help of diamond paste. Then etching was done in Kroll solution for 20 seconds. Samples were viewed with a microscope. The internal structures of the samples were examined by scanning electron microscopy (SEM). The X-Ray Diffraction method (XRD) was performed by scanning in the range of 30-80 degrees. Figure 1 shows the tests and analyses performed on the test samples.

Table 1. Ti6Al4V chemical composition (%)

Al	V	Fe	C	O	N	H	Ti
5.5-6.5	3.5-4.5	0-0.25	0-0.08	0-0.13	0-0.05	0-0.012	Balance

Table 2. Classification of Ti-6Al-4V parts.

Code	Samples
As-received	Ti6Al4V specimen
LW	Laser welded Ti6Al4V
HT1	Laser welded followed by heat treatment (HT) at 800 °C for 2 hours, furnace cooling (FC)

HT2	Laser welded followed by HT at 950 °C for 2 hours, FC
HT3	Laser welded followed by HT at 1080 °C for 2 hours, FC

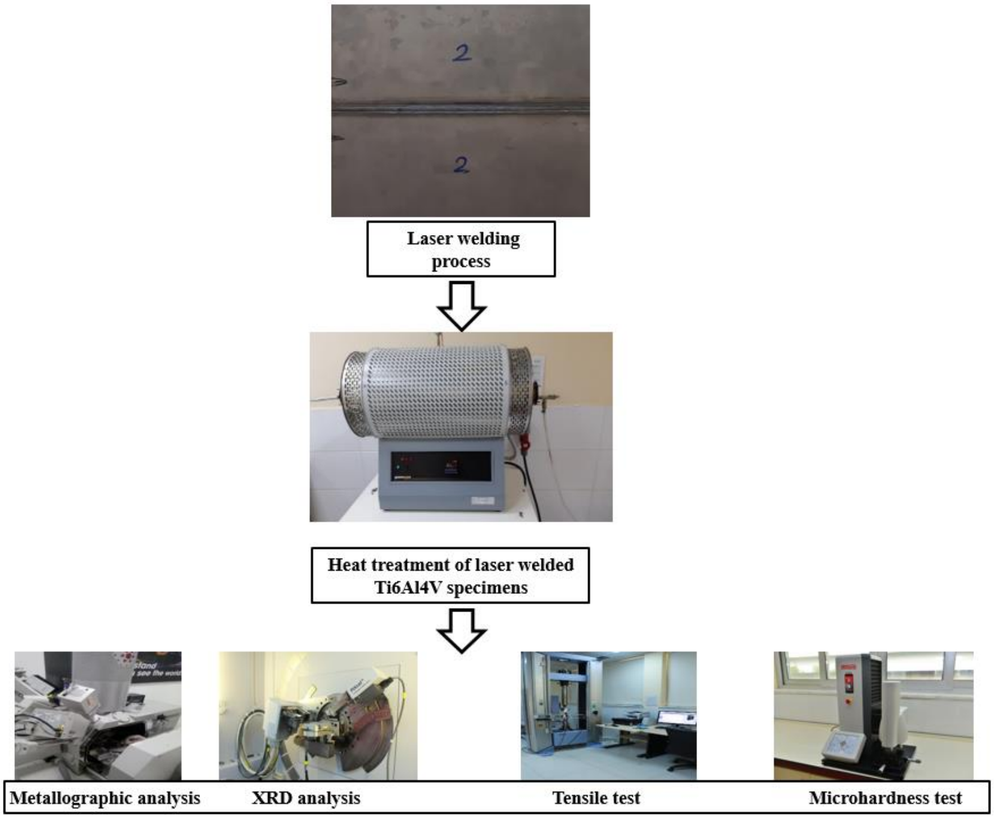

Figure 2. Test and analysis steps for Ti6Al4V.

3. Results and Discussion

An optical microscope view of laser-welded Ti6Al4V material is given in Figure 3. A needle-like martensitic structure was observed in the melting and heat-affected zones due to the sudden cooling after welding. In the base metal region, there is a coaxial spherical structure. This structure plays a role in increasing fracture toughness and supporting strength [12]. In the microstructure, light-colored sections represent the α phase with a tight-packed hexagonal lattice structure, and dark-colored sections represent the β-phase with a volume-centered cubic lattice structure. The change in the internal structures of the weld zone of the Ti6Al4V samples after heat treatment is given in Figure 3(d-f). After the 800 °C heat treatment, it is seen that the martensite structure begins to dissolve, although there are some needle-like structures (Figure 3(d)). Widmanstatten morphology was observed after heat treatments at 950 °C and 1080 °C. It was observed that the grain structure became coarser after the β transformation temperature in the heat treatment (1080 °C). In addition, it was determined that a lamellar structure was formed in the weld area after the heat treatment processes.

Looking at the SEM images in Figure 4(a,b), it was determined that the laser-welded test specimens had micro-cracks in the weld area. It has been reported that this situation has a decreasing effect on mechanical property values [13]. Due to this micro-crack structure seen in the weld area, the welding efficiency of the welded joint was determined to be 75.3% compared to the base material. In addition, when the base material is examined, it is seen that α and β phases are together in the structure, but the α phase structure is more dominant. When the laser-welded sample is examined, there are α' peaks in the structure due to the sudden cooling (Figure 4(c)). Heat treatments were effective in increasing the peak levels. This is attributed to grain coarsening due to heat input.

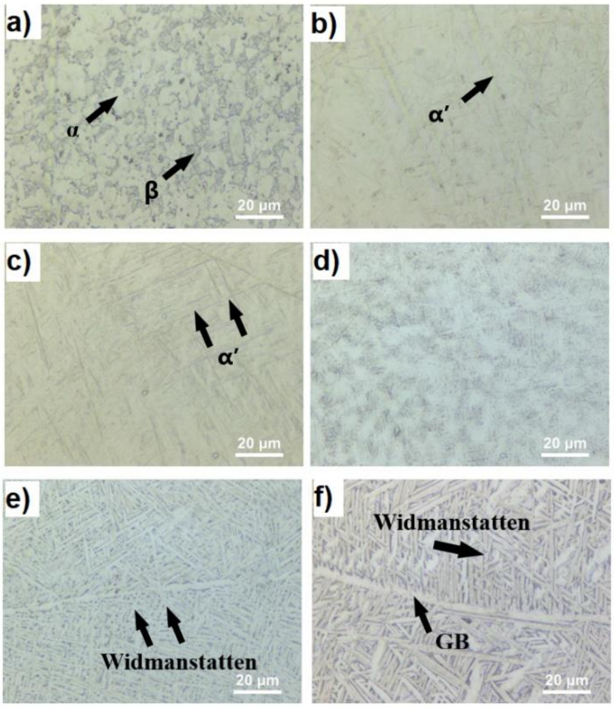

Figure 3. Microstructure of laser welded samples: a) base material, b) heat affected zone, c) weld zone, d) weld zone (HT1), e) weld zone (HT2), f) weld zone (HT3, GB: Grain boundary).

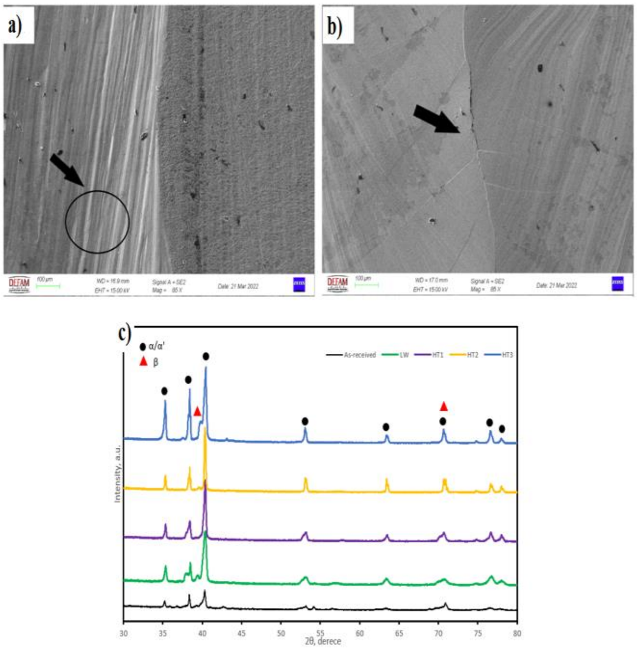

Figure 4. SEM view of the samples: a) General view, b) detail view, c) XRD analysis.

3.1. Mechanical Evolution

A view of the hardness distribution of the laser-welded Ti6Al4V part is given in Figure 5. The microhardness value of welded parts is related to the microstructure. The martensite structure in the weld zone and the heat-affected zone are the reasons for the increase in hardness value. The hardness values of the rolled samples did not decrease when heat treatment was applied at 800 °C. On the contrary, there was some increase in hardness in the weld area (Fig. 5(b)). This is due to the presence of a certain amount of martensite phase in the structure of the parts after the heat treatment process. Even after three heat treatments, it is observed that the microhardness of the weld zone is higher than the welded sample without the heat treatment process. Researchers reported that with the decrease in β phase volume with post-weld heat treatment applications, hardness would increase, especially in the weld area [14]. In addition, a slight tendency to decrease hardness values after heat treatment was also observed at β transformation temperature. This is due to the increase in the β phase, which is more ductile than the α phase.

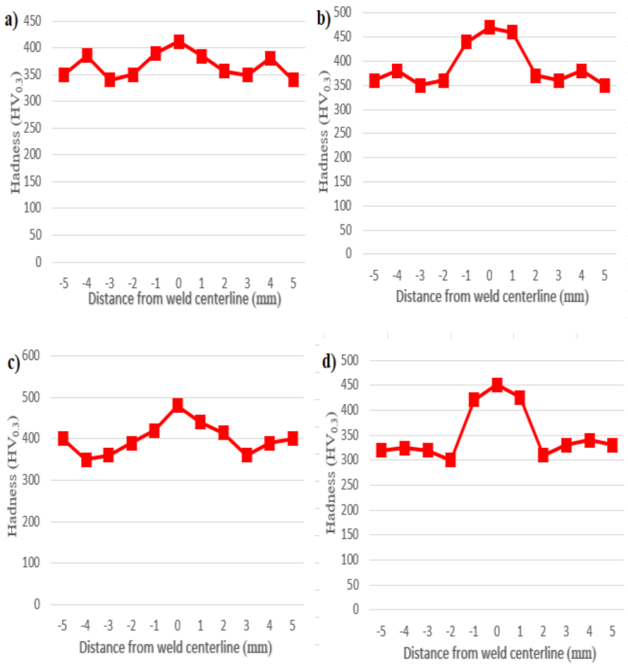

Figure 5. The hardness value of the samples: a) LW, b) HT1, c) HT2, d) HT3.

The tensile test results of laser welded Ti6Al4V material heat treated at different temperatures are given in Table 3. The welding efficiency of the laser welded (LW) sample was determined to be 75.3%. It is seen that the mechanical values of the laser welded sample are lower than the base material due to micro-cracks in the weld area. The best mechanical properties of the heat-treated and laser-welded Ti6Al4V parts were determined after the heat-treatment process at 1080 °C. After this heat treatment, the tensile strength value was determined to be 853.6 MPa, and the elongation was determined to be 8.8%. The elongation value of the base material was determined to be 15.7%. When the heat-treated samples were examined, it was determined that the elongation value increased with the increase in temperature. It is estimated that this situation is caused by grain coarsening due to the increase in temperature [11].

The tensile strength and elongation values of laser welded rolled Ti6Al4V samples are given in Figure 6. The elongation value of the base material was determined to be 15.7%. When the heat-treated samples were examined (HT1, HT2, and HT3), it was determined that the elongation value increased with the increase in the heat treatment temperature. It is estimated that this is due to grain coarsening due to increased heat treatment temperature [11].

Table 3. Ti6Al4V tensile test values.

	Yield strength [MPa]	Tensile strength [MPa]	Elongation [%]	Weld Efficiency (%)
As-received	933.5	1002.4	15.7	
LW	668.3	755.2	7.6	75.3
HT1	556.7	648.2	5.1	64.7
HT2	628.9	712.7	7.7	71.1
HT3	745.6	853.6	8.8	85.2

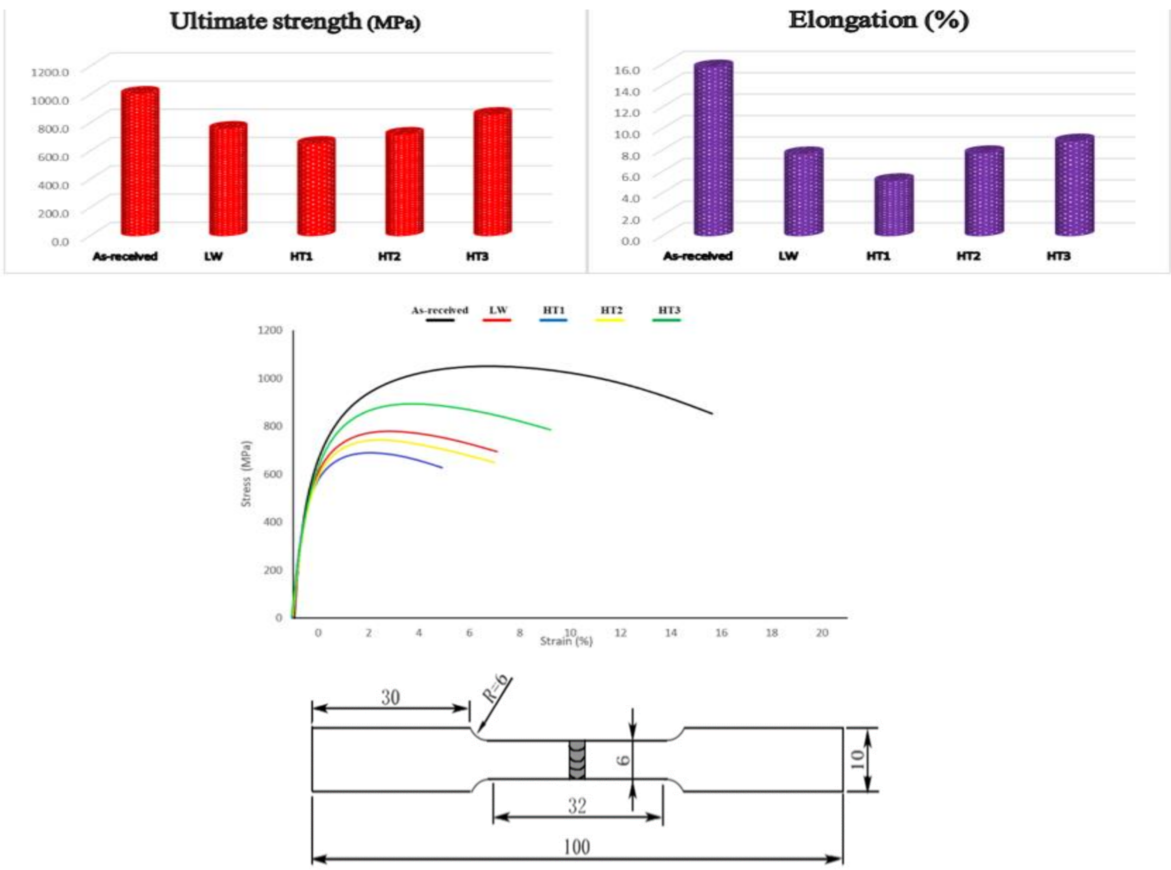

Figure 6. Tensile test results of parts.

4. Conclusion and Suggestions

The results of the microstructural changes and mechanical properties that occur in the material when heat treatment is applied to the laser-welded Ti6Al4V material are given below:

• When the microstructures of welded samples are examined, the weld area and the heat-affected zone are martensitic, while the base metal zone consists of equiaxed α + β phase structures. In addition, it was determined that the martensitic structure in the weld area was replaced by the lamella Widmanstatten morphology, especially after the heat treatments at 950 °C, and 1080 °C with the increase in temperature.

• The hardness of the welding zone of the materials joined by laser welding was higher than the base metal. It was determined that the hardness values decreased slightly after heat treatment at 1080 °C. This is thought to be due to grain coarsening.

• As a result of the tensile test, it has been observed that the strength of laser-welded parts is lower than that of the base material. This is thought to be due to microcracks detected in the weld area. The best mechanical properties of welded parts were observed after heat treatment at 1080 °C.

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Contributions of the authors

Writing, Experimental study: Kadir Aydın; Supervising: Mustafa KARAMOLLA.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethic.

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