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Weldability of Grade 2 Titanium Sheets with Pulsed Nd:YAG Microlaser Welding Filler and Without Filler

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Laser welding method is widely used in the welding of different materials. Deep penetration, low heat input, narrow heat affect zone, low stress-strain, and distortion are important features of this welding method as compared to other joint methods. Today, it is possible to see the applications of laser welding in the repair of precious metals, moulds, and machine parts. The laser welding method is preferred in the manufacture of many parts of precious metals. Titanium and particularly Grade 2 alloys are used in a wide range of applications, from medical applications to the aerospace industry applications. Since titanium is made of precious metals, it is of great use in manufacturing without much scrap. In the joints made by welding, it is estimated that the amount of scrap loss will decrease as a result of the potential to predict the distortion that the material will undergo and to provide more controlled planning of the current production. In this study, the weldability of 0.6 mm sheet materials with laser butt-welding was investigated. The effects of pulsed micro laser welding parameters on the microstructure, mechanical properties, and surface morphology of the fractures were investigated. As a result of the microstructure examination, it was found that cross-section narrowing was seen without filling welding. Fracture of the welded joints occurred in the base metal, showing an ultimate tensile strength of approximately 248 MPa with an elongation of 26.7 %.

Keywords: Grade 2 titanium, micro laser welding, Nd:YAG, welding parameters.

1. INTRODUCTION

Titanium and titanium alloys are among the most preferred metals today in automotive and medical fields thanks to their high corrosion resistance and low density. These alloys are appropriate to use in environments like the aerospace industry, in which lightweight, high resistance elements, and internal engine components are required. Titanium also shows appropriate functionality at elevated temperature ranges [1]. Grade 2 has excellent specific tensile and corrosion resistance, making it ideal for use mainly in petrochemical plants and surgical implants [2]. As the alpha and the beta stabilizers respectively, aluminium and vanadium form a two-phase $\alpha + \beta$ alloy [3, 4]. Grade 2 alloy is quite popular in turbine disks, compressor blades, airframe, and space capsule structural components ring for jet engines, pressure vessels, rocket engine cases, helicopter rotor hubs, fasteners, critical forgings requiring high strength-to-weight ratios, and medical or surgical devices due to its high strength and low density, accompanied by such features as good tensile and creep properties up to about 300 °C [5, 6]. Titanium and titanium alloys are among the precious metals, and it is this fact that requires meticulous care in manufacture with those metals as well as in the welding method for joining titanium alloys with thin sections [7, 8]. Laser welding has an important role in joining titanium alloys with thin sections. Lasers are instrumental devices in amplifying light by stimulated emission of radiation [9]. Low heat input and low distortion rates, accompanied by the appropriate level of heat treatment make titanium alloy welding a preferable option [10]. Balasubramanian et al. (2008) reported that by welding titanium with pulsed current tungsten inert gas, they obtained fine grain structure in the weld fusion zone [11].

Based on the literature review, it is seen that thick titanium alloys with more than 1 mm are generally preferred with the pulsed current tungsten inert gas welding. Besides, it is seen that the use of the laser welding method has increased, although the various welding methods have been frequently used in recent years [12, 13]. In this study, Grade 2 titanium alloy with a thickness of 0.6 mm was welded using a pulsed Nd:YAG microlaser welding method. The effects of pulsed current Nd:YAG microlaser welding on the fusion zone microstructure, mechanical properties and weldability were investigated in welding fine titanium alloys. In this framework, it is thought that the present paper will be a reference work in welding micro-thickness titanium and its alloys by pulsed micro laser welding method.

2. MATERIAL AND METHODS

2.1. Materials and welding procedure

The chemical composition of the Grade 2 titanium sheet material used in the experimental study is given in Table 1.

Table 1. Chemical composition of Grade 2 Ti alloy (wt.%)

Fe	O	C	N	H	Ti
0.3	0.25	0.1	0.03	0.0015	99.31

The plates were mechanically wire brushed with acid pickling in an HF solution and then cleaned with acetone

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before welding. Grade 2 materials were butt-welded through pulsed Nd:YAG microlaser welding method and welded. Ti sheet materials with 0.6 mm thickness were joined before welding, and the zone was cleaned. Welding parameters used in welding are given in Table 2. The schematic representation of the welding method used in the experiment is given in Fig. 1.

Table 2. Welding parameters used in this study

Pulse energy, J	Pulse frequency, Hz	Pulse duration, ms	Welding speed, mm/s
8.2	18	5.3	1.5
Output power, W	Focal length, mm	Laser pulse energy, J	Laser pulse current, A
< 300	100 mm	3 – 21	80 – 150

Laser beam diameter, mm	Laser fluence, J/cm^2	Peak intensity, W/cm^2
0.4	3 – 7	98 – 107

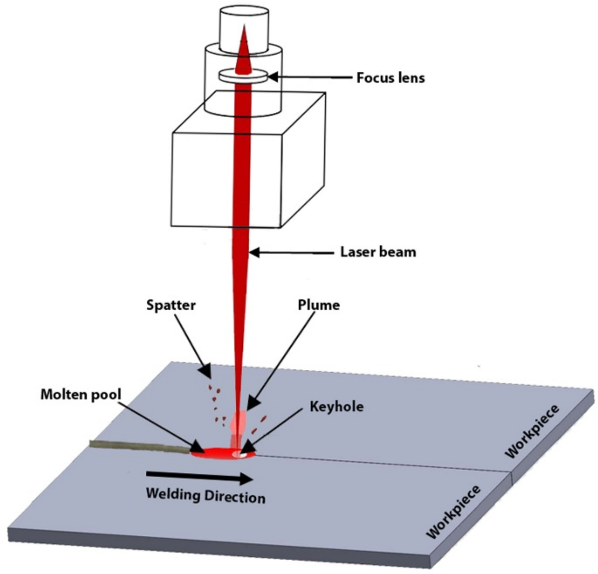


Fig. 1. Schematic of pulsed Nd:YAG microlaser welding

The microstructure along the weld cross-section was observed through an optical microscope. The welding area is given in Fig. 2. The weld metal surfaces were cleaned before figuring so that a better vision of the weld could be held.

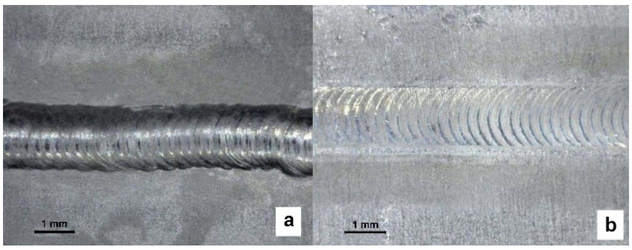


Fig. 2. a – the weld metal top surface with filler; b – without filler

2.2. Microstructural characterization

Following the welding, the metallographic procedure was applied to observe the microstructure of the samples. The samples were cut with a water jet for observation followed by mounting. Following the standard grinding and polishing, samples were etched with 190 ml pure water + 5 ml nitric acid + 3 ml hydrochloric acid + 2 ml hydrofluoric acid etching Keller's Reagent. The etched samples were imaged through an optical microscope and SEM. Weld metal images were taken at low amplifying rates by using Leica optical microscope.

2.3. Scanning Electron Microscopy (SEM) and energy-dispersive spectrometer (EDS) analysis

Since the Grade 2 titanium sheet is 0.6 mm thin, the weld area needs to be examined in detail. Therefore, the Quanta FEG 250 scanning electron microscope (SEM) was used for this examination. In the welded area examination process and following the tensile test, fracture surface investigation was performed using SEM. The laser-welded sample weld zone was analyzed with an energy dispersive spectrometer (EDS) to determine the change in alloy concentration (wt.%).

2.4. Microhardness test

The microhardness of the welds was measured in the melting zone (FZ), the heat-affected zone (HAZ), and the base metal (BM) in the longitudinal direction under 100 g load, with a dwelling time of 10 sec. Hardness was measured at 100 μm intervals through the welding process. Hardness measurements were made with a micro Vickers hardness tester.

2.5. Tensile test

Tensile samples of pulsed Nd:YAG microlaser welded sheets were prepared under tensile standards (ASTM E8) as shown in Fig. 3. The tensile test was carried out on the SHIMADZU AG-XD tensile testing machine with a maximum load of 50 kN and a pulling speed of 2 mm/min at room temperature. After the tensile test, the broken surface was examined using a Scanning Electron Microscope.

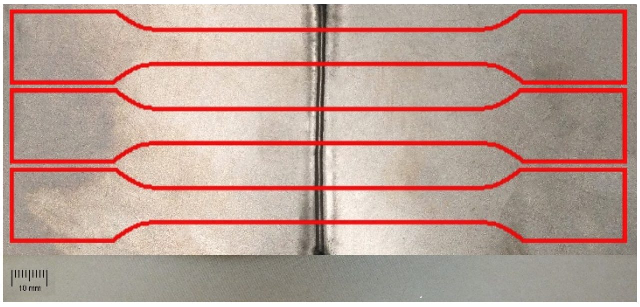


Fig. 3. Schematic view of tensile test specimens cutting plan according to ASTM E8

3. RESULTS AND DISCUSSION

The experimental results of pulsed Nd:YAG microlaser welding of 0.6 mm thin Grade 2 titanium alloy are discussed in the following subsections.

3.1. Microstructural examination

The microstructure of the base metal, heat affected zone (HAZ), and the weld zone are investigated in this section. The image of the sheet material microstructure is given in Fig. 4. HAZ structure is seen in α very narrow section of the microstructure. The microstructure of the Grade 2 alloy has two phases. The equiaxed intergranular β structure is seen in a white zone while the equiaxed globular α structure is seen in black grains. Similar microstructures were also observed by other researchers [14 – 17].

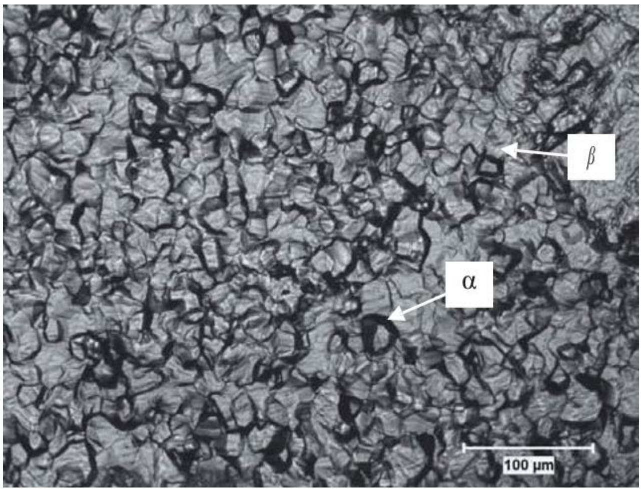


Fig. 4. α (black) and β (white) grained base metal microstructure

Balasubramanian et al. (2011) reported that the α phase was black and the β phase was white in titanium and its alloys, and the grain sizes changed depending on the heat flow [18]. Yoganjaneyulu et al. (2018) stated that the microstructure of titanium Grade 2 consists of α phase and β phases in their microstructure study in their experimental studies [15]. It has been determined that the coaxial grain morphologies in the base material lose the coaxial structure and turn into a column-like structure as the cooling rate increases after micro laser welding. Liu et al. (2012) stated that as the cooling rate of pure titanium increases in laser welding, the coaxial grain structure turns into a columnar structure [19]. The welding with filler can be seen in Fig. 5.

It can be seen in Fig. 6 that HAZ (heat-affected zone) formed in α very narrow zone and equiaxed material microstructure turned into acicular weld structure. The welding process was carried out on the samples most suited for welding. It was observed that welding in the form of an adhesion came out in some samples, and therefore pores were formed in weld metals. The optical microstructure of the welded fusion zones shows characteristic acicular features. The weld without filler is given in Fig. 6. It can be seen in Fig. 6 that HAZ (heat-affected zone) formed in a very narrow zone, and the microstructure of the equiaxed material underwent grain coarsening in the weld zone. It was also observed that material thickness decreased with double side welding. Acicular formed in columnar white (β) while black (α) grains emerged in laser-welded weld pool of Grade 2 Ti alloy.

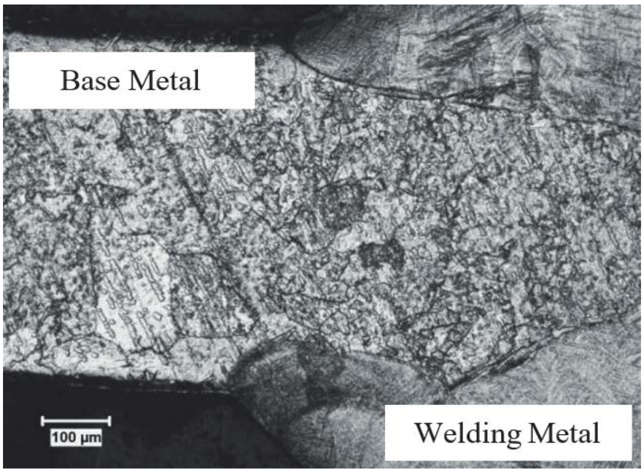


Fig. 5. Weld microstructure carried out with filler, typical optical microstructure near the centre of the as-welded fusion zone

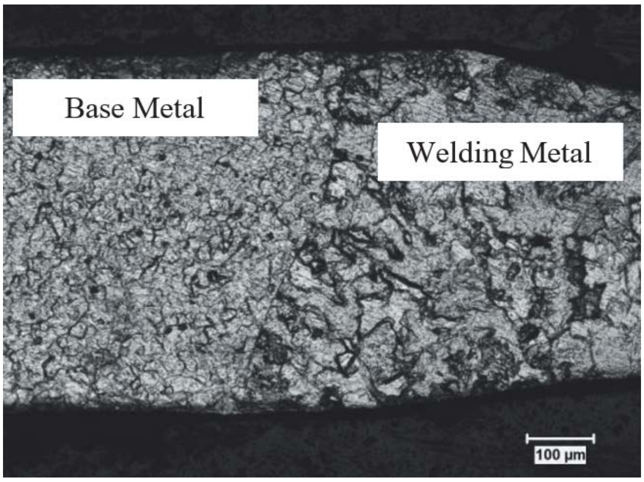
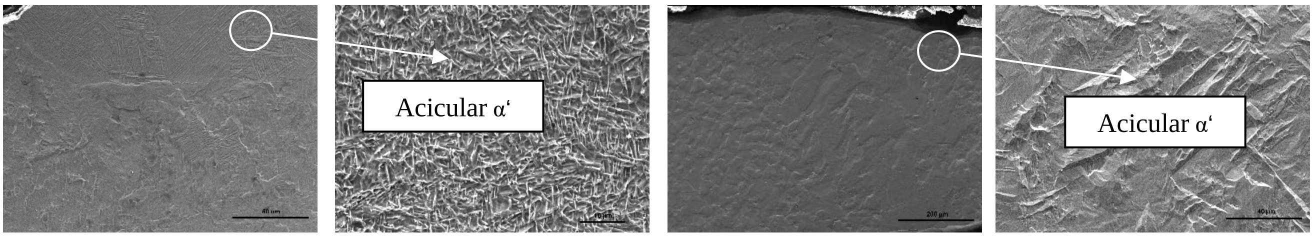


Fig. 6. Weld microstructure without filler

3.2. SEM and EDS analysis

SEM image in Fig. 7 is analyzed after pulsed microlaser welding; α′ and α have been shown to occur in a mixed microstructure composed of phases. At the same time, it is seen that the amount of α′ acicular phase is more than that of the other α phase in welding with pulse current. Kumar et al. (2020) found similar results in their study [20]. Due to the high cooling rate in the microlaser welding process, it is seen that the microstructure consists of acicular α′. Gao et al. (2013) determined that the microstructure is formed out of acicular α′ as a result of rapid cooling in the laser welding process [21].



a b c d

Fig. 7. SEM image of pulsed Nd: YAG microlaser samples of the cross-section of the butt joint: a – filler welding transition region; b – filler welding, welding region; c – without filler welding transition region; d – without filler welding, welding region

Xu et al. (2014) showed that the cooling rate has a determinant role in microstructures of all weld fusion zones, affected greatly by the scanning speed of laser welding [22]. Torkamany et al. (2012) showed that weld porosity came out in the pulsed laser welded joints of pure Ti [23]. Fig. 8 shows the EDS analysis of the weld zone.

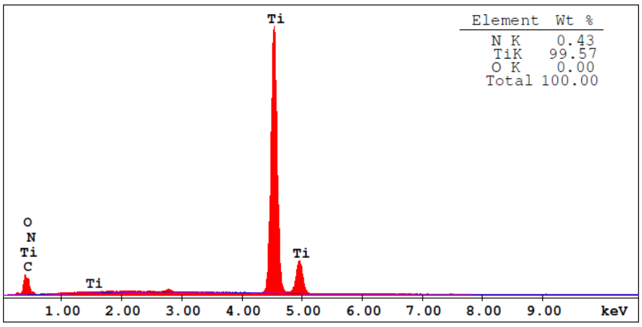


Fig. 8. EDS analysis showing the distribution of elements at weld zone

3.3. Microhardness test

The graphic of the results obtained by micro Vickers hardness measurement is given in Fig. 9. This figure shows the microhardness changes from the centre of the fusion zone towards the base metal. When the graphic is examined, it is determined that there is a fluctuation as a result of hardness measurements. The reason for this can be attributed to the high cooling rate in micro laser welding of Grade 2 titanium alloy. The high cooling rate affected the microstructure, uneven grain growth, and distribution of the acicular alpha phase. As a result, fluctuation occurred as a result of hardness. The highest hardness value in the fusion zone was found as 182 $HV_{0.1}$ for filler welding and 195 $HV_{0.1}$ for without filler welding. Prasath et al. (2020) stated that there is a significant increase in hardness with the transformation of phases in the material microstructure to α' martensite [13]. The hardness value obtained in this study also increases similarly.

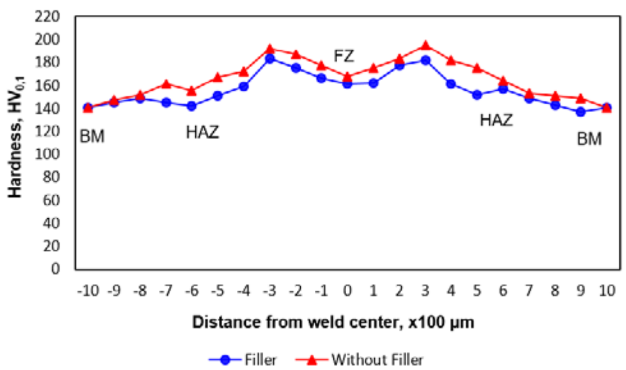


Fig. 9. Micro Vickers hardness measurement for Grade 2 titanium micro laser welding

3.4. Fractography analysis of the tensile samples

It has been determined that the tensile strength of the welded specimens is not lower than the tensile strength of the base material. All of the filler and without filler welded samples undergoing tensile test were fractured from the base material. Fig. 10 shows the stress-stroke curves of the base metal with and without filler welding samples. SEM image of the broken surface of the fractured samples is given in Fig. 11. The similar appearance of all samples resulted in the use of a single image. Pulse microlaser welded samples showed ductility with regard to the applied load and resulted in neck formation in the base metal as shown in Fig. 12.

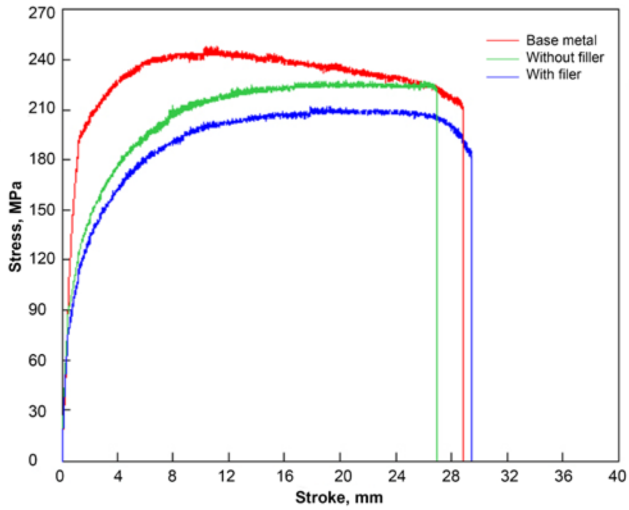


Fig. 10. Stress–Stroke curve for base metal and welded sheet and fractured samples

Fig. 11 shows that the broken sample has fine dimples/voids on the fractured surface. Karpagaraj et al. (2015) found a similar rupture type in their study [24].

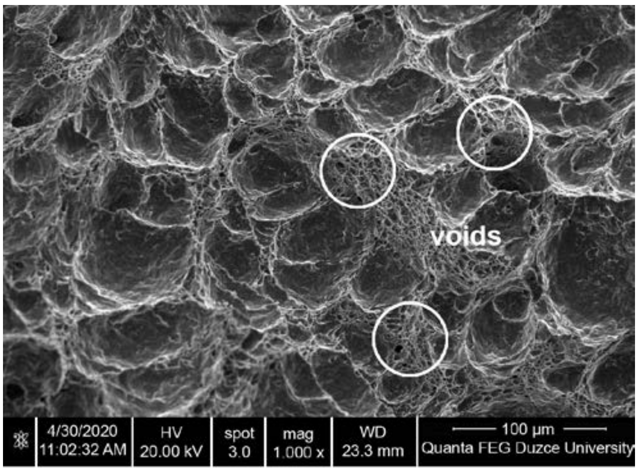
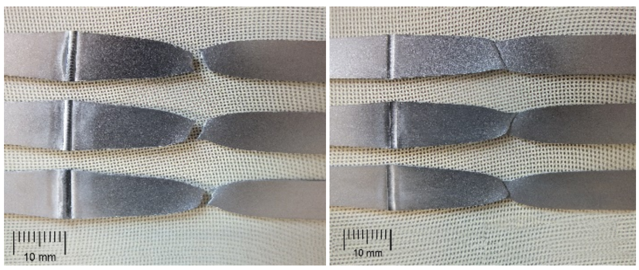


Fig. 11. Tensile test fractured sample surface SEM image



a b

Fig. 12. a – fractured sample from the base metal with filler; b – without filler

The maximum stress and maximum elongation amounts obtained as a result of the tensile test of the base metal and with and without filler welding samples are given in Table 3.

Table 3. Result of the tensile test

Name/units	max_stress, MPa	max_elongation, %
Base metal	248.438	26.7080
Without filler	228.906	24.3910
With filler	202.240	20.2320

From the values in Table 3, it is seen that the base metal, without filler welded and the filler welded sample, the ultimate tensile strength results are close.

4. CONCLUSIONS

The results obtained in the light of experimental studies are given below:

1. It has been observed that thin titanium Grade 2 alloys of 0.6 mm are suitable for welding by pulsed micro laser welding method.
2. After the microlaser welding process, it has been observed that the microstructure consists of an acicular α′ structure as a result of rapid cooling.
3. A significant size of grain coarsening was noticed in the welded fusion zone, and the coaxial grains in the HAZ were larger than the grains in the base metal. As a consequence, it has been determined that the grain coarsening decreases as it passes from the fusion zone to the base metal.
4. The maximum hardness value in the fusion zone was measured to be 182 $HV_{0.1}$ for with filler welding and 195 $HV_{0.1}$ for without filler welding
5. As a result of the tensile test, all samples fractured from the base metal. Ultimate tensile stress was measured to be 248 MPa. In other samples, it was measured to be 202 MPa in filler welding and 228 MPa without filler welding.

To sum up, it is seen that the previous studies have frequently worked on relatively thick materials (more than a thickness of 1 mm). On the other hand, this paper demonstrates the weldability of a thin titanium alloy of 0.6 mm, successfully.

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