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EFFECT OF LASER ENERGY ON WELD STRENGTH FOR NEODYMIUM YTTRIUM ALUMINUM GARNET (ND:YAG) AT λ = 1.06 µm

Khairi Khazman Zulkiflee, Nurul Sabihah Zakaria*

School of Distance Education, Universiti Sains Malaysia (USM), 11800 USM, Pulau Pinang, Malaysia

**Corresponding author: nurulsabihah@usm.my*

Abstract

The effect of different laser welding energies on neodymium yttrium aluminium garnet was studied and discussed. Results for weld strength at 0.9 Joules, 1.0 Joules and 1.1 Joules laser energy had been investigated for the butt joint of titanium plate with 0.01-inch thickness using pull test method. The results showed that the laser energy had effect on weld strength of the welded samples. The average of weld strength results show increasing with the increasing on laser energy from 0.9 Joules, 1.0 Joules and 1.1 Joules which is 29.968 N, 32.444 N and 34.605 N respectively. Differences of laser energy influence the weld strength as higher weld strength was observed at higher laser energy. The highest weld strength observed is 36.785 N at 1.1 Joules. These results show the laser energy gives higher weld strength for titanium plate.

Keywords: Laser energy, weld strength, neodymium yttrium aluminium garnet.

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Introduction

Laser is a beam of concentrated light energy generated at a specific wavelength. Lasers deliver energy in the form of electromagnetic radiation beams. Laser energy is a variable input and deemed as critical parameter to weld performance as the laser energy might influence the weld strength of the manufacturing product. The differences of laser energy will result in difference of weld strength. Ideally, higher laser energy will provide higher weld strength as the higher energy may penetrate deeper into both welded components for fusion (Fahlström, 2019). Laser energy produced during laser welding process will create a heat to melt the welded parts together. The laser welding processes are intended to create either an electrical joint, structural joint or temporary joint between components. However, excessive laser energy might reduce the weld strength which impact the fusion of the welded joint material whereas over penetration and defect formed. This study focused to determine the effect of weld strength for different laser energy using Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser at 1.06 micrometres (µm) wavelength while maintaining the same welding parameter and parts used. Several parameters can influence the weld strength such as welding distance, material, pulse shape, frequency/rate, pulse duration and beam size (Marya et al., 2005; Radaj, 1996; Li et al., 2011; Casalino et al., 2010; Shamini, 2017; Torabi & Kohalan, 2018; Kumar et al., 2019). Aforementioned parameters were kept constant in this study. This study is important in order to obtain a good product quality and longer the welded joint lifespan which having a high weld strength without defect.

It should be noted that the radiation for Nd:YAG laser energy with wavelength of 1.06 µm is amongst the purest spectral forms. The laser rod used in Nd:YAG laser welders is a synthetic crystal of Yttrium Aluminum Garnet (YAG). The YAG material is the host material which is containing a small fraction of neodymium called the active element. The YAG crystal is physically hard, stable, optically isotropic and has good thermal conductivity. These characteristics allows the laser operating at high average power levels produces by the lasing material called Neodymium (Nd^{3+}). The laser rod dimensions are around 15 millimetres (mm) and a length of 200 mm, selected based on the power to ensure the crystal quality and thermal management of the rod. The thermal heating occurred at high energetic levels to generate a lasing action (Chandra Singh et al., 2012).

Laser welding widely used as an industrial tool in joining method because of its advantages such as low thermal distortion of the work piece due to low heat input, narrow heat affected zone, deep and narrow welds can be produced with high metallurgical quality, high welding speeds, flexible process which suited to automation and operate in conjunction with robots (Kundu et al., 2019; Williams, 1997; Cao et al., 2003; Schubert et al., 2001; Romoli & Rashed, 2015). According to Bachmann et al. (2016), welding depth penetration was related to the high laser power. Chua et al., (2019) had studied in laser welding aluminium alloy shown depth penetration increase with increasing of laser energy. In addition, Hekmatjou et al. (2018) studied also prove that the weld penetration for 5456 aluminium alloy increase with increase of laser power increase using Nd:YAG laser welding. Oyyaravelu et al. (2016) had investigated laser welding using Nd:YAG laser on high strength low alloy (HSLA) SA516 grade 70 boiler steel and concluded that the weld depth penetration increase with increase of laser power due to increase of heat input. In Yan & Shi, (2019) investigation on Al/Cu joints shear strength resulted to be increase and then decreases with the increase of the laser power which the maximum is about 99.8 MPa with the 2.45 kW laser power. Bahrami et al. (2019) had investigated on 17-4 PH stainless steel shown that the tensile strength and weld penetration increase respective to the increasing of laser energy. Zheng et al. (2008) had studied the influence of laser welding parameters on Nickel Titanium (NiTi) alloy wires and concluded the weld quality was found related to laser power where high energy resulted in good mechanical properties such as higher fracture strength. Kumar et al. (2018) had concluded that the size of heat affected zone and width of the weld increase affected by laser energy increase for Monel 400 alloy sheet whereas, the maximum tensile strength was obtained at energy of 10J. Samad et al. (2019) had studied on the aluminium alloy EN AW 6082 using a varies of laser power and welding speed shown the depth penetration and the width of heat affected zone is increase with the increase of laser power. Gnanasekaran et al. (2021) had investigated the effect of Nd:YAG laser power on AISI 301 austenitic stainless steel steel joints which resulted deeper penetration and higher tensile strength at higher laser power.

The weld strength is influence by the laser energy absorption of a material during welding process. As two component parts are brought together, a beam of laser light is generated by the laser welder at a specific wavelength. When a laser beam strikes, the absorptive material absorbed and converted into heat, which begins melting the absorptive part at the component joining location. The component then cool and solidify, which creates a strong joint.

Pull testing were performed using Chatillon pull tester. Pull testing was commonly used to determine the physical strength of the material. In this study pull testing were performed using a motorised pull tester at speed of 1 inch per minutes. The pull tester measured the peak force to separate the test samples apart. Generally, higher laser energy can produce higher weld strength which completely melt the parts. However, low or excessive laser energy also can produce lower weld strength (Li et al., 2011; Fahlström, 2019). According to Fahlström (2019) and Hatim et al. (2012), lower tensile strength observed in laser welding which does not weld the whole depth due to lack of penetration. According to Hatim et al. (2012), Chen et al. (2019) and Li et al. (2011), if the laser power kept increased, the tensile strength decreased as the peak tensile strength is corresponded to the complete penetration without any obvious defect. An excessive laser power can cause defect which led to decreased in tensile strength. As the outcome for higher laser energy, the welded component is expected to provide higher pull strength during pull test.

Methods

Three runs had been conducted in the experiment based on different laser energy of Neodymium Yttrium Aluminum Garnet (Nd:YAG) at 1.06 µm wavelength which are 0.9 Joules, 1.0 Joules and 1.1 Joules. Thirty (30) samples were used for each run. Rofin SWMP 6002 Nd:YAG laser welding machine and titanium plate was used in this study using butt joints. Butt joint is where two pieces of material are placed side by side and the weld is made at the interface between two materials. Firstly, the reference voltage for desired energy output and the welding parameters was adjusting per experiment run plan. Parameter was fix at frequency: 0 Hz, pulse duration: 2.5 milisecond (ms) and collimator: 6. Parameter setting was verified at the beginning of each run and set at 0.9 Joules, 1.0 Joules and 1.1 Joules laser energy respectively prior testing for each run. Each sample was prepared and labelled according to the number sequence (sample 1 to sample 30) for each run prior laser welding. Each sample was placed into the welding chamber and the laser spot alignment was aligned at the joint position for the welding operation. During welding operation, argon was injected at 8 liters per minute (l/min) through a nozzle, creating an inert protective atmosphere. Each welded joint was subjected for the 100% visual inspection to determine a good sample was produced. Defect samples will be eliminated from the experiment to avoid inconsistent results. After visual inspection, each good sample had been pulled tested. The pull testing was performed by Chatillon TCD225 pull tester.

Result and Discussion

Results for Run 1, Run 2 and Run 3 are shown in supporting information section. Laser energy against pull strength shown higher pull strength observed for higher laser energy per Figure 1. Higher pull strength is observed at 1.1 Joules compare to 0.9 and 1.0 Joules. Based on the test results, all samples from Run 1, Run 2 and Run 3 passed visual inspection. Pull testing is performed to determine the maximum force attained for each sample. A destructive test is performed whereby the test sample is pulled to a specified force until the test sample separated. Overall, the results show the lowest pull strength is 28.134 N in Run 1 and highest pull strength is 36.785 N in Run 3.

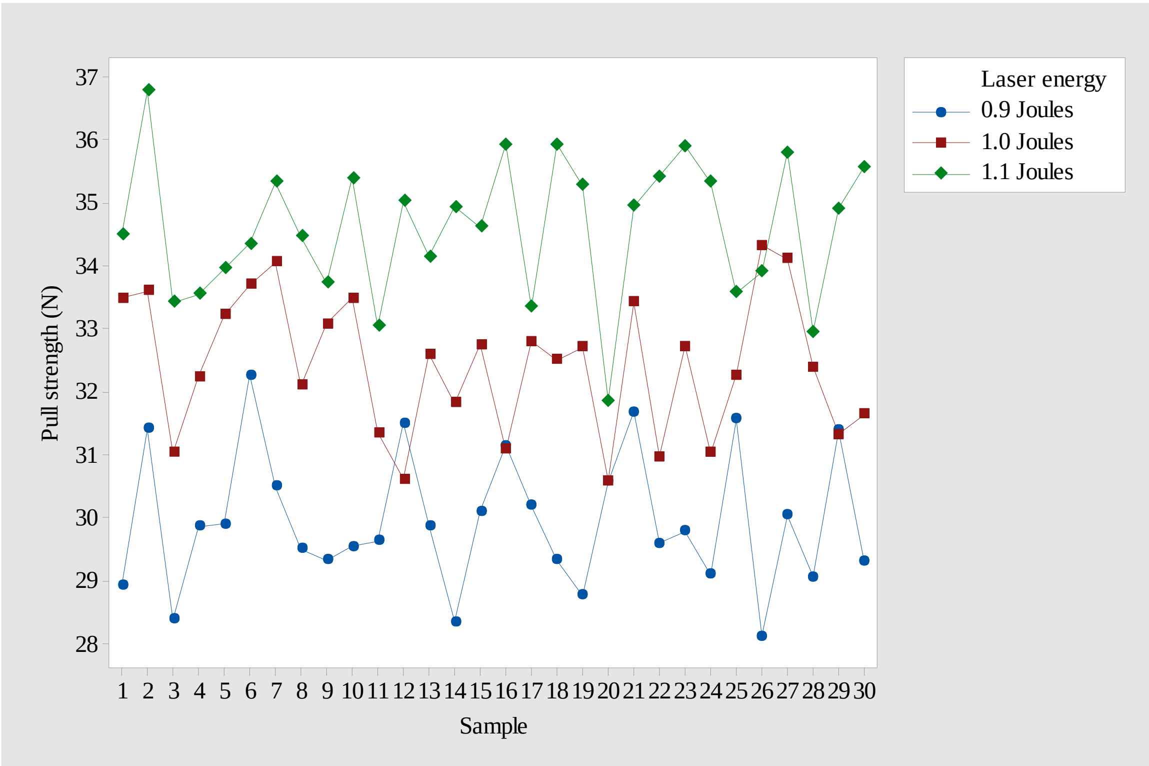

Figure 1. Laser energy against pull strength shown higher pull strength observed for higher laser energy

The average of pull strength for the samples showing an increasing trend respectively to increasing of laser energy which are 29.968 N for Run 1, 32.444 N for Run 2 and 34.605 N for Run 3 as shown in Figure 2. Meanwhile, standard deviation is showing the consistency around 1 N. All the results are summarized in Table 1**.** Based on the results, the minimum, maximum and average value of pull strength for 0.9 Joules, 1.0 Joules and 1.1 Joules increase with increasing of the laser energy. In this study, the pull strength increasing resulted by the increasing of laser energy due to higher laser energy was penetrated deeper into the welded material which maximizes the weld depth compare to lower laser energy. The increasing of weld depth penetration influences the increasing area of molten welded area.

So, the weld strength increase as larger force is required to break the welded samples. Therefore, these results showing a higher weld strength can help to improve a welded joint lifespan which larger force is required to break the welded joints apart.

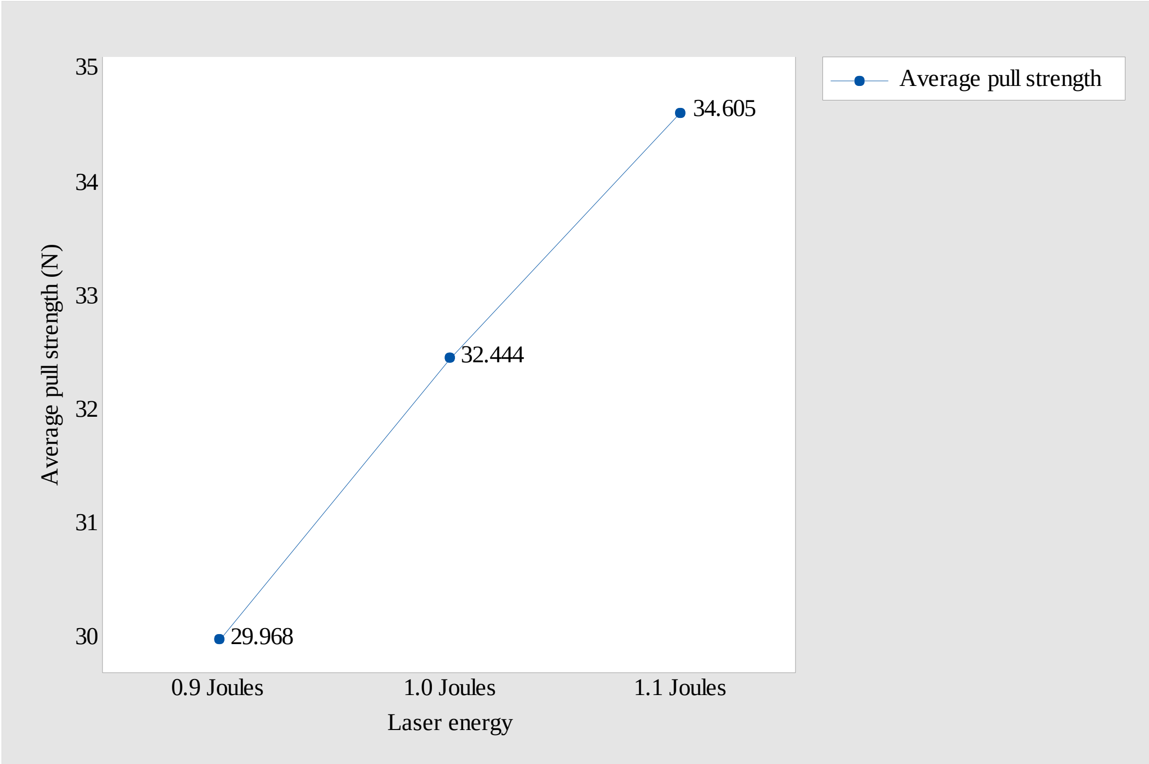

Figure 2. Laser energy against average pull strength

Table 1. **Pull strength**

Process Output	Number of run	Number of sample	Mean (N)	Standard Deviation (N)	Min (N)	Max (N)
Pull Strength	Run 1	30	29.968	1.082	28.134	32.270
	Run 2	30	32.444	1.095	30.602	34.339
	Run 3	30	34.605	1.106	31.870	36.785

Conclusion

The effect of weld strength based on laser energy of Neodymium Yttrium Aluminium Garnet (Nd:YAG) at 1.06 µm wavelength had led to the conclusion where all pull strength data showed an increasing trend. Besides that, by comparing the pull test data, the average pull strength was increase with a percentage 1.23 % from 0.9 Joules to 1.0 Joules and 0.92 % from 1.0 Joules to 1.1 Joules. Laser energy increase, then weld strength will increase was experimentally proven. The higher weld strength was influence by higher energy which penetrate deeper into both welded components for fusion. This may beneficial to titanium-based product such as in aircraft, fastener and medical devices.

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Supporting Information

Test results for Run 1 at 0.9 Joules laser energy

Run 1		
Sample	**Visual Inspection: (Pass/Fail)**	**Pull Strength (N)**
1	Pass	28.934
2	Pass	31.425
3	Pass	28.400
4	Pass	29.868
5	Pass	29.913
6	Pass	32.270
7	Pass	30.513
8	Pass	29.512
9	Pass	29.335
10	Pass	29.557
11	Pass	29.646
12	Pass	31.514
13	Pass	29.891
14	Pass	28.356
15	Pass	30.113
16	Pass	31.158
17	Pass	30.202
18	Pass	29.335
19	Pass	28.779
20	Pass	30.580
21	Pass	31.692
22	Pass	29.601
23	Pass	29.802
24	Pass	29.112
25	Pass	31.581
26	Pass	28.134
27	Pass	30.046
28	Pass	29.068
29	Pass	31.403
30	Pass	29.312
	Average	29.968

Test results for Run 2 at 1.0 Joules laser energy

Run 2		
Sample	**Visual Inspection: (Pass/Fail)**	**Pull Strength (N)**
1	Pass	33.493
2	Pass	33.605
3	Pass	31.047
4	Pass	32.248
5	Pass	33.227
6	Pass	33.716
7	Pass	34.072
8	Pass	32.115
9	Pass	33.093
10	Pass	33.493
11	Pass	31.358
12	Pass	30.624
13	Pass	32.604
14	Pass	31.825
15	Pass	32.760
16	Pass	31.092
17	Pass	32.804
18	Pass	32.515
19	Pass	32.715
20	Pass	30.602
21	Pass	33.427
22	Pass	30.980
23	Pass	32.737
24	Pass	31.047
25	Pass	32.270
26	Pass	34.339
27	Pass	34.116
28	Pass	32.404
29	Pass	31.336
30	Pass	31.648
	Average	32.444

Test results for Run 3 at 1.1 Joules laser energy

Run 3		
Sample	**Visual Inspection: (Pass/Fail)**	**Pull Strength (N)**
1	Pass	34.494
2	Pass	36.785
3	Pass	33.427
4	Pass	33.560
5	Pass	33.960
6	Pass	34.361
7	Pass	35.339
8	Pass	34.472
9	Pass	33.738
10	Pass	35.406
11	Pass	33.049
12	Pass	35.028
13	Pass	34.161
14	Pass	34.939
15	Pass	34.628
16	Pass	35.940
17	Pass	33.360
18	Pass	35.940
19	Pass	35.295
20	Pass	31.870
21	Pass	34.961
22	Pass	35.428
23	Pass	35.918
24	Pass	35.339
25	Pass	33.582
26	Pass	33.916
27	Pass	35.806
28	Pass	32.960
29	Pass	34.917
30	Pass	35.584
Average		34.605