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Adequated Laser Parameters for a Cerclage Wire Joining in a Modern Femur Surgery

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Abstract

The aim of this research is determination of process - window parameters for a fiber - laser welding on a cerclage wire. The proposed process has been feasibility studied in a modern femur surgery. A good weld appearance, free oxidation and having a good joint strength are a target and need to discuss under effect of laser parameters. A stainless steel wire 316L was a cerclage wire specimen. A flare weld on lap joint of wire diameter of 1.6 mm is a designed joint. The charge voltage of laser irradiation and the multi - frequency are the main effect variables for controlling a suitable fusion weld. The area of the adequated laser parameters from experiment are the charge voltage range of 80 - 110 volt and multi - frequency of 6 - 9 Hz with the pulse width of 3 ms. The welded length of 5, 10, and 15 mm were tested on tensile test to qualify the joint strength from the adequated laser parameters. All of welded length have ultimate tensile strength more than a common cerclage joint.

Keywords: *cerclage wire, laser welding, ultimate tensile strength*

Introduction

Cerclage wire is a common procedure of orthopaedic surgeons for internal fixation or helps as a tool for arranging femoral bone fracture. Currently, this surgery method has an indication for the treatment of bone fractures had multiple positions such as periprosthetic fracture, femoral fracture or patellar fracture, etc. [1-6]. Cerclage wire is using a wire to wrap around bone fracture then twist the end of wire around the two bones together to form a knot in Figure 1(a). In addition, there is cerclage cable which has a device called crimp to use for lock the cable in Figure 1(b).

Cerclage wire has still had a problem in fixation failure (untwist) which cerclage wire failure often occurs at the innermost turn of the twist [4]. As a result, surgeons must be repeated surgery which affects patients and surgeons severely. The problem of fixation failure is a result of broken wire before bones are connected. The weak of cerclage wire is position begin to twist wire due to surgeons fasten wire too tight as a result wire lose properties of biomechanics. Furthermore, if surgeons fasten wire too little. As a result wire loosening [9, 16] after surgery and cause to fixation failure as well. Therefore, the knot of wire is a critical point to measure achievement in treatment.

In this research, study feasibility in a modern femur surgery by laser welding on a cerclage wire which cerclage wire double loop in Figure 1(c) is the cerclage configuration that has been studied to design experiments. In preliminary studied, laser welding experiments were conducted on a flare weld condition by studying the effect of laser parameters to control the fit weld profile on lap joint of wire diameter of 1.6 mm. This experiment is designed to find the adequate area of laser parameters including ultimate tensile strength of joint strength from laser parameters and welded length of 5, 10, and 15 mm by tensile testing. Because of the laser has low heat and high accuracy properties. Therefore, laser welding is applied to this research to improve the quality and strength of common cerclage joint.

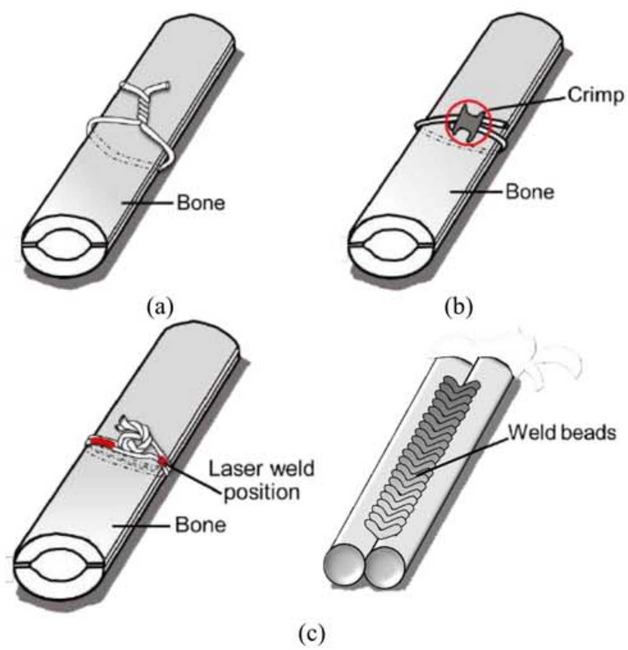

Figure 1 Type of cerclage (a) cerclage wire, (b) cerclage cable, and (c) cerclage wire (double loop) with laser welding

Experiment procedure

Material and experimental setup

Stainless steel wire 316L with diameter 1.6 mm was used in this experiment. The experiment was performed on laser welding machine AHL – Laser (model XBW- 400). The beam source of laser welding in this experiment is Nd:YAG (wavelength 1064 nm) and focused length of laser machine is 80 mm. For laser welding process starts with arrangement of the two stainless steel wires with jig fixture. The specimen is in axis with laser head which laser beam is radiated emitted from the laser head which weld bead between two stainless steel wires was called flare weld. And apply argon gas on and under specimen during welding which gas will be passed the gas nozzle to cover the welding area to prevent oxidation in Figure 2 which in this experiment used defocused length 56 mm, argon gas shielding at flow rate 10 L/min, and travel speed 75 cm/min set to constant.

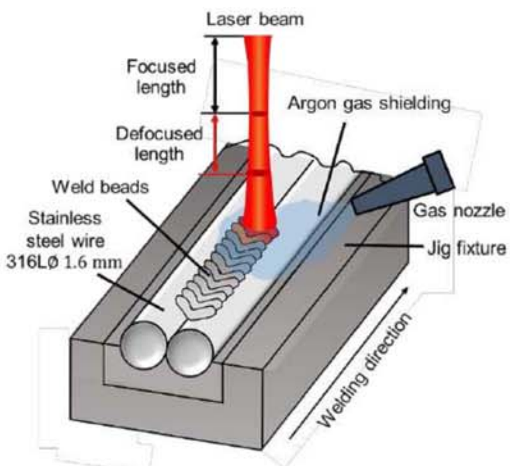

Figure 2 Experimental schematic

Inspection of weld appearance

Adjustment laser parameters to find the upper and the lower bound from inspection of weld appearance that can weld on stainless steel wire 316L properly by adjusting charge voltage (volt), multi-frequency (Hz), and pulse width 3 ms set to constant in Figure 3. Figure 3 found that the upper of charge voltage at 110 volt and multi-frequency at 12 Hz weld appearance oxidation due to overheating at high charge voltage and heat accumulation faster at high multi-frequency adjustment. Furthermore, heat from welding inappropriate with wire dimension. Therefore causes oxidation and burns on the weld beads. The lower of charge voltage at 80 volt and multi-frequency at 3 Hz lack of fusion due to insufficient heat to melt the wire. Therefore, the rank of acceptable laser parameters in this experiment are charge voltage 80 – 110 volts and multi-frequency 6 – 12 Hz (Note: At multi-frequency 3 there is too much gap between weld bead be the cause of cavity defect which maybe affects the joint strength.)

In this research, three studied laser parameters are charge voltage, multi frequency, and pulse width to evaluate effect of melting from adjust laser parameters on stainless steel wire in aspect of width and depth which can design the rank of laser parameters for experiment from inspection of weld appearance in Table 1.

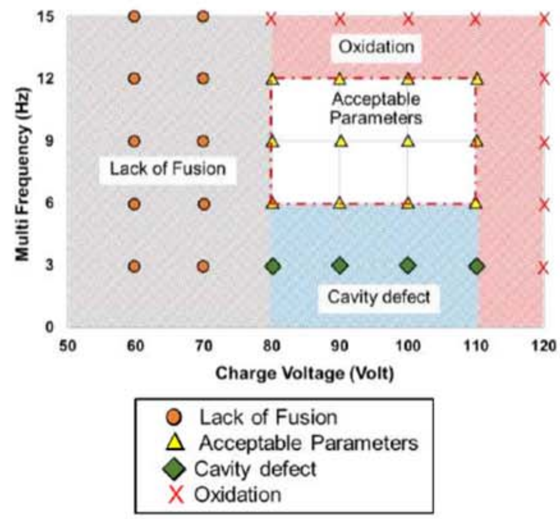

Figure 3 Inspection weld appearance of laser parameters

Table 1 Laser Welding Parameters

Parameters	Level			
Charge Voltage (Volt)	80	90	100	110
Multi Frequency (Hz)	6	9	12	
Pulse width (ms)	3			
Argon Gas Shielding (L/min)	10			
Travel Speed (cm/min)	75			
Defocused Length (mm)	56			
Beam diameter (mm)	1.76			

Tensile testing

Verification of the mechanical properties of joint strength from laser weld was evaluated by the tensile testing to determine the strength of the weld beads which depending on the parameters of the laser and the length of welding which will evaluate ultimate tensile strength to find the adequate area of laser parameters and length of welding. Ultimate tensile strength must be within acceptable range or more than previous research. The experimental variables were three variables in Table 2 which were conducted an on flare weld condition. Tensile testing was performed on Universal testing machine under constant cross-head speed 12.5 mm/min.

Table 2 Variables for testing the tensile strength

Variables	Level			
Charge Voltage (Volt)	80	90	100	110
Multi Frequency (Hz)	6	9	12	
Length of welding (mm)	5	10	15	

(Note: pulse width 3 ms set to constant)

Results and Discussion

Effect of laser parameters on weld bead width

Figure 4 shows the example of oxidation region at high multi-frequency 15 Hz, a good weld appearance or nice ripples at acceptable area, and lack of fusion at low charge voltage 70 volt from inspection weld appearance which results from experiment found that increasing of charge voltage and multi-frequency effect on weld shape and weld bead width. After that, measurement from weld appearance to study and compare weld bead width from charge voltage and multi-frequency adjustment. Figure 5 shows the weld bead width results at charge voltage 80, 90, 100, and 110 volts (Define: multi-frequency 6 Hz and pulse width 3 ms set to constant) and Figure 6 at multi-frequency 6, 9, and 12 Hz (Define: charge voltage 80 volt and pulse width 3 ms set to constant). Increasing of charge voltage and multi-frequency, bead width was increased due to heat to melting was increase and gap area decrease include sound bead was increased due to multi-frequency of welding increase respectively especially the charge voltage adjustment which from results found that at charge voltage 110 volt is the highest weld bead width indicates that there is the most sound bead.

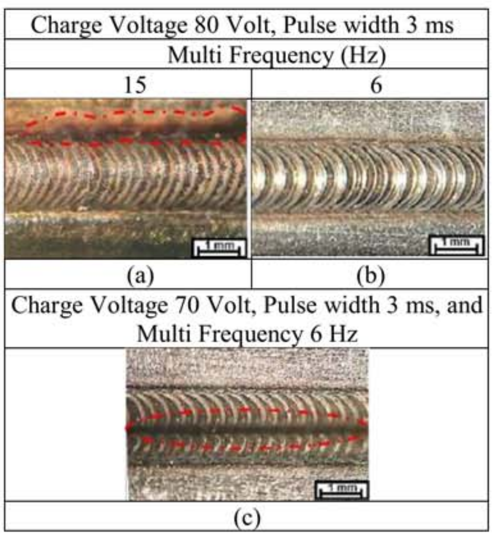

Figure 4 Weld appearance (a) Oxidation, (b) nice ripple (c) Lack of fusion

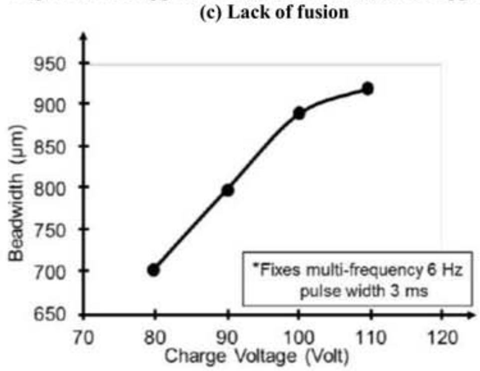

Figure 5 Effect of charge voltage on weld bead width

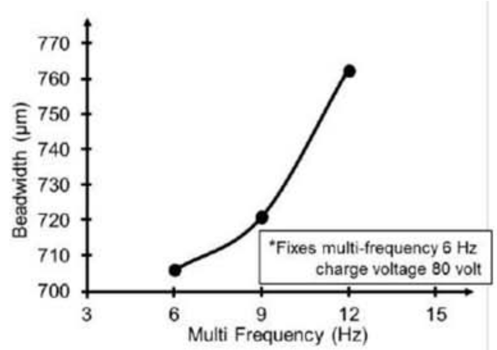

Figure 6 Effect of multi-frequency on weld bead width

Effect of laser parameters on area of fusion, and throat size

Figure 7 shows the example of macro structure from the cross section at charge voltage 80 and 90, at multi-frequency 6, 9, and 12 Hz (Define: pulse width 3 ms set to constant). The macro structure was used for measurement and analysis area of fusion and throat size of the influence of heat in melting stainless steel wire 316L from charge voltage and multi-frequency adjustment. Figure 8 and 9 shows result of macro analysis are increasing of charge voltage and multi-frequency, area of fusion and throat size was increase. In particular, increasing charge voltage results in area of fusion and throat size were increased obviously. At charge voltage 110 volt and multi-frequency 12 Hz are the highest areas of fusion and throat size consequently, there is a tendency to have the highest tensile strength. Therefore, increasing of area of fusion and throat size, resulting in more tensile strength as well.

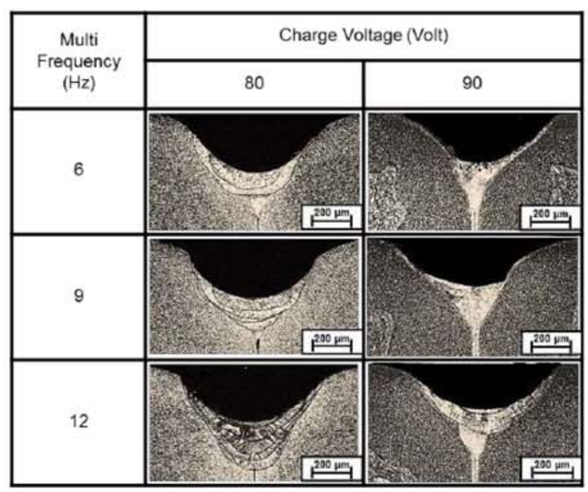

Figure 7 Macro structure (cross section)

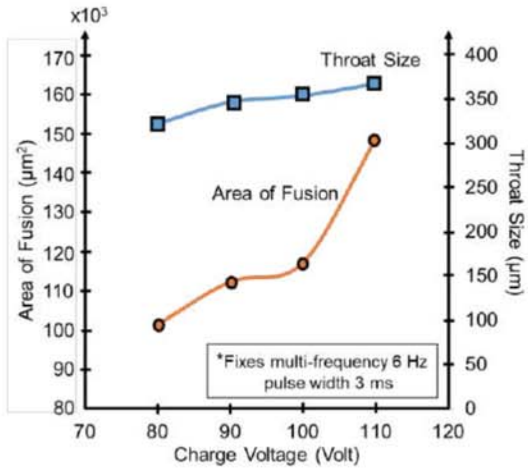

Figure 8 Effect of charge voltage on area of fusion and throat size

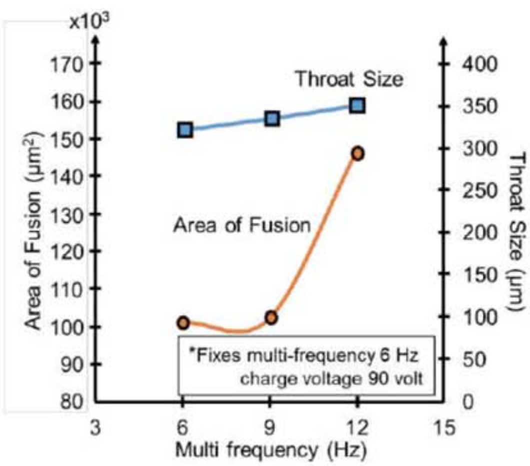

Figure 9 Effect of multi-frequency on area of fusion and throat size

Effect of laser parameters and length of welding from tensile testing

Results of the ultimate tensile strength in Figure 10 at weld's length of 5 mm by adjust charge voltage 80, 90, 100, and 110 volts and multi-frequency at 6, 9, and 12 Hz (Define: pulse width 3 ms set to constant) and in Figure 11 at weld's length of 10 mm. Figure 10 and 11 found that increasing of charge voltage and multi-frequency effect on the ultimate tensile strength. In other words, increasing of laser parameter as a result of ultimate tensile strength increase especially increasing of charge volt due to charge voltage adjustment increase, resulting in increased in sound bead which results in increased strength from tensile testing which from results found that at charge voltage 110 volt is the highest ultimate tensile strength. However, still need to consider additional heat input as well. Increasing of length of welding from 5 to 15 effect on ultimate tensile strength more than adjusting the laser parameters which in Figure 10 and 11 found that ultimate tensile strength increased from 800 to 1400 when compared to the same charge voltage 80 volt and multi-frequency 6 Hz. At weld's length of 15 mm is the maximum ultimate tensile strength and occur failure at base metal which show that weld beads is stronger than base metal and the rang of ultimate tensile strength at weld's length of 15 mm approximately 2000 – 2200 N.

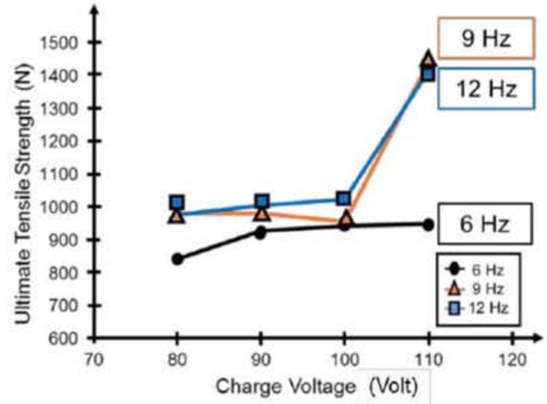

Figure 10 Effect of laser parameters on ultimate tensile strength (length of welding 5 mm)

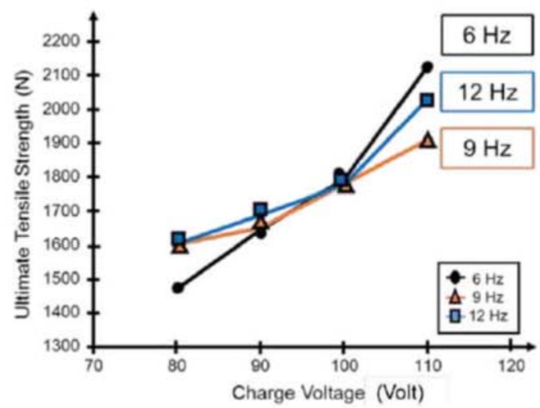

Figure 11 Effect of laser parameters on ultimate tensile strength (length of welding 10 mm)

Optimal laser parameters

Results from inspection of weld appearance and ultimate tensile strength from adjustment of laser parameters and length of welding can analyze to find the optimal laser parameters for welded on stainless steel 316L. For criteria to select optimal laser parameters in this study are low heat input and high ultimate tensile strength or acceptable ultimate tensile strength in Figure 12.

Figure 12 shows the process - window laser parameters which adequate area of laser parameters and example of weld appearance from adequate area have a good weld appearance or nice ripples, free oxidation, and good joint strength. Increasing of charge voltage and multi-frequency adjustment results in higher heat input and ultimate tensile strength. Furthermore, increasing of welded length results in higher ultimate tensile strength as well which length of welding 5 mm is the minimum ultimate tensile strength but still within acceptable range. From experiment at length of welding 5, 10, and 15 mm include laser parameters in the acceptable area found that all of welded length have ultimate tensile strength are within acceptable range and more than a common cerclage joint. Therefore, in this study will consider from heat input to find adequate area which the rank of adequate laser parameters are charge voltage 80 – 110 volt, multi-frequency at 6 – 9 Hz due to low heat input and free oxidation. (Pulse width 3 ms set to constant)

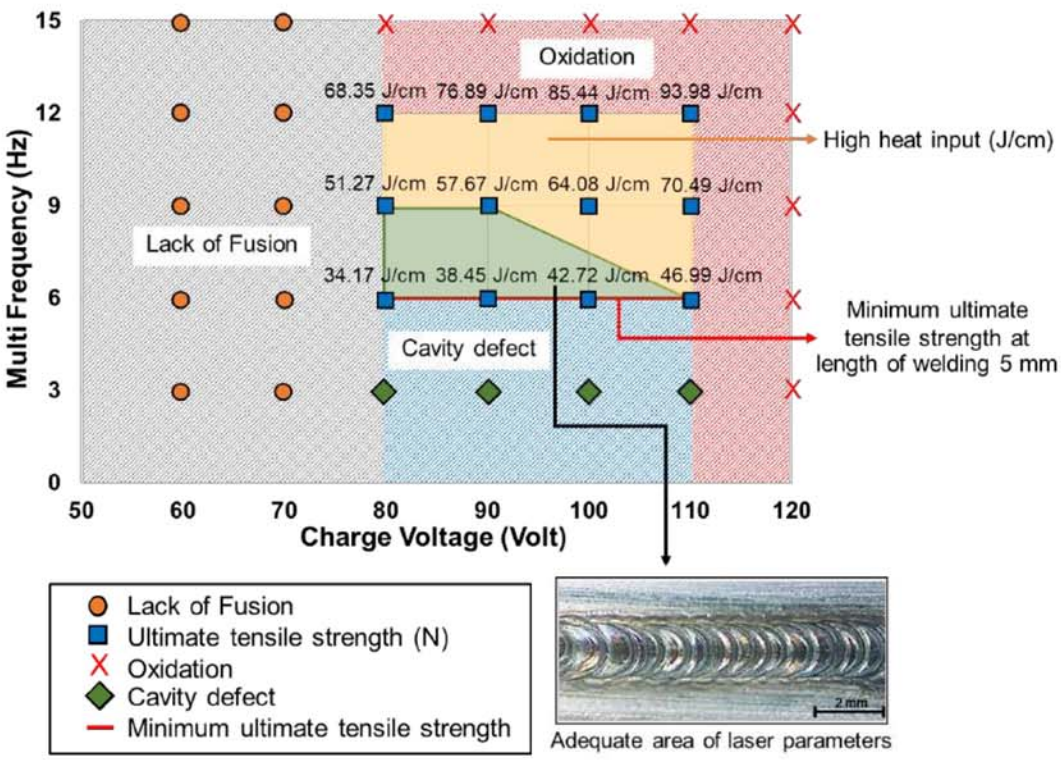

Figure 12 Adequate laser parameters

Discussion for the application and future work

In this study used the technology of laser for welded on stainless steel wire 316L of a flare weld condition to study the range of tensile strength from laser welding and resolve the problem from untwisting of common cerclage wire including increase the strength due to laser welding is suitable for small pieces that require high precision. Results
from this experiment found that laser welding can weld on stainless steel wire 316L and weld appearance of adequate laser parameters have a nice ripple and free oxidation. In part of ultimate tensile strength are within acceptable range and higher than previous study. Laser welding on stainless steel wire must be aware of safety of heat energy control during the welding process and after welding so that it is not harmful to the patient when used in actual treatment.

Therefore, in the future work will use adequate laser parameters from this study to apply with laser welding on cerclage wire with an artificial bone condition. In addition, study of heating simulation and actual experiment for investigating thermal behavior from laser welding on cerclage wire which temperature must be within acceptable range.

Conclusion

In this research is a preliminary study about the feasibility of laser welding and effect of using laser weld on stainless steel wire 316L of a flare weld condition. It can be concluded that:

1) Acceptable criteria of the adequate area of laser parameters from laser welding are acceptable ultimate tensile strength and more than common cerclage joint, low heat input, and free oxidation.

2) The increasing of charge voltage and multi-frequency affect to increase bead width, area of fusion, and throat size which the result found that charge voltage is the main impact on weld size and weld shape.

3) The increasing of laser parameters especially charge voltage and length of welding effect to increase ultimate tensile strength but increasing of length of welding effect on ultimate tensile strength more than adjusting the laser parameters.

4) Length of welding 5 and 10 mm failed at weld beads but 15 mm failed at base metal which shows that weld bead is stronger than base metal. Moreover, it shows that length of welding affect to ultimate tensile strength more than laser parameters adjustment.

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