The Application of Pulsed Laser Welding in Optical Unit Splicing

Xiong Wang, Changji Hao, Jiabin Chen, Rendong Xu, Lei Zhang,

Charles Jeremy Brow, Shaobo Ma, Di Wu, Bin Zhang

Hengtong optic-electric Co., Ltd

Suzhou, Jiangsu, P.R. China

wangxiong@htgd.com.cn

Abstract

The existing Submarine Cable are usually made up of stainless steel tube optical fiber unit structure. Because of the limitation of fiber length and equipment of the production of optical fiber unit, a full length of the fiber unit can't meet the requirement of the lager length Submarine Cable or Photoelectric Composite Cable. So the method of tube splicing was needed to extend the length of single fiber unit. In this paper a method of pulsed laser welding was applied in the splicing after finished splice tube. The tube was spliced by crimping after the fusion of fiber ends, and than weld the circular edge of the tubes' overlap. Test on the finished splice tube showed sufficient mechanical strength and excellent air tightness. Test on the inside fibers beside the welding showed that welding almost have no effect on the mechanical strength and fatigue performance of the fibers.

Keywords: Submarine cable; optical fibers; optical unit; splicing; steel tube; pulsed laser welding.

1. Introduction

Submarine cables often have very long lengths of more than 50km. however, during the production of the optical unit (steel tube), there is always a risk of a weld failure that cannot be the maximal reel size that fits in the machinery [1]. In order to overcome these problems, some splicing methods for optical unit have been developed. At present, it's very popular to connect the two tubes that adopt the method of overlapping and then crimping the overlap. But there some deficiencies about it, such as the air tightness is very poor, so the subsequent machining process must be very careful and take some measurements to increase the air tightness. A new excellent steel tube connection technique is urgent need to improve the situation.

The Pulsed Laser Welding is a highly precise welding method with a narrow heat affected zone, high joint strength and welding aesthetic. The laser was use as an heat source of Pulsed Laser Welding. The average input energy of the Pulse laser welding is small, and very suitable for the small parts which need more strict conditions of thermal conductibity. The overlapping pulse can achieve good air-tight seal effect, which will be very suitable for the welding of overlap of optical unit.

The fibers May be exposed to adverse environment when welding, especially the heat generated by the pulsed welding. The mechanical reliability of such fiber systems is a matter of concern. Therefore, to assess reliability it's necessary to determine the mechanical properties of the fiber in terms of strength and fatigue behavior. The most important methods for determining the mechanical properties of high-strength fiber are loading in tension and two-point bending [2]. Because the optical fiber exists crackles itself and also produce the micro-crack as well as local damage, the fatigue behavior of the optical fiber become the main problem we care about [3].

Hengtong Marine Cable Systems (HMCS), a professional manufacturer of submarine cables has carried out some research about the tube splice, especially the application of the Pulsed Laser Welding in the tube splice. And the Reliability of the splices was evaluated by tensile strength test and air tightness test of tube. Also the effect of the welding on the fibers beside the welding point was evaluated by dynamic tensile test and two point bending test of the fibers.

2. Welding experiment for splicing

2.1 Preparing experimental samples

2.1.1 Raw materials

Table 1. Raw materials

Raw material	Features	Remarks
Optical Units Tubes (304 Stainless Steel)	O.D.=2.7mm, WallThickness.=0.20mm, Tube Length=250mm	with 24 fibers and a thixotropic filling compound inside
Splice Tubes (304 Stainless Steel)	O.D. 2.1mm, Wall Thickness.0.20mm, Tube Length 250mm	with a thixotropic filling compound inside
Fbers	G652D, SingleMode	-

2.1.2 Preparing welding samples

The simulative splicing process starts cutting the tube of optical unit (φ2.7mm) to the length of 250mm, with the fiber (length =1200mm, fiber cores = 24) and fiber filling gel insided. The second step is to cut the spice tube to the length of 250mm. Then slide the splice tube into the optical unit tube carefully and adjust to the final location to ensure the overlap length is 120mm as it showed in Figure 1 and Figure 2. Keep mind, the whole operation need to be very careful to avoid any damage to the fibers.

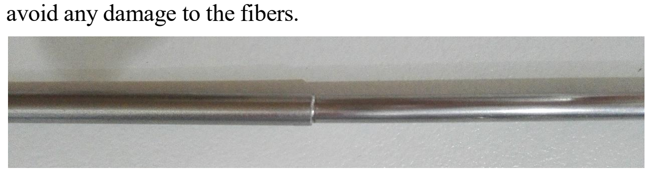
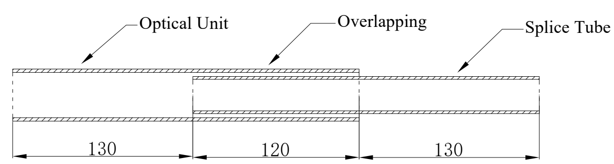


Figure 1. The splicing experiment samples



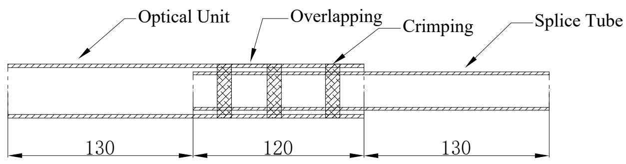


Figure 2. The sketch of the experiment samples

(a)Sample without crimping; (b) Sample with crimping

2.1.3 Experiment equipment and test equipment

Table 2. Experimental Equipment and test equipment

Equipment	Number / version	Manufacturer
Pulsed laser welder	HAN'S PB300CE	Han's Laser
Tensile testing machine	WDW-50	Shanghai Hualong
Microcomputer control electron Universal testing mach	WDW-0.2J	Shanghai Bairuo
Two-point bending tester	FIBER SIGMA	---
Helium Mass Spectrometer LeakDetector	UL1000Fab	INFICON

2.2 Tube splicing by pulsed laser welding

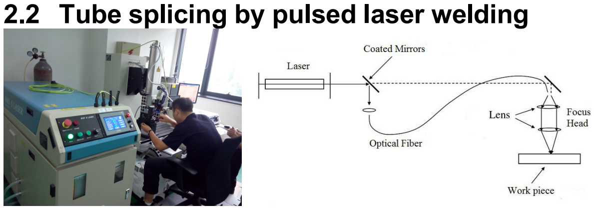


Figure 3. Equipment and schematic representation of Pulsed Laser Welding

The equipment we used for welding is showed in Figure 3. The main parameters as follows. Laser wavelength: 1064nm. Laser maximum output power: 25W. The maximum laser pulse energy: 25J. Pulse Time: 0.1~50ms. Pulse frequency: 1~50Hz. Diameter Of fiber core:0.2mm. The diameter of Laser welding spot is about 0.4mm with argon gas protecting.

2.3 Choosing wedding type

2.3.1 Weld geometries

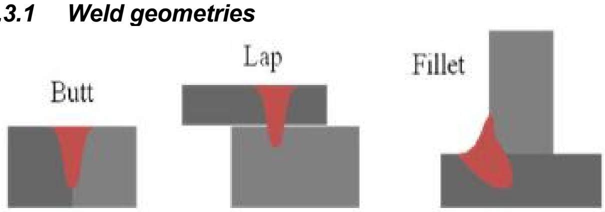


Figure 4. Three key weld geometries

From the Figure 4, the butt welding can't be used in tube splicing because the edges of optical unit tube and splice tube can't touch each other for different sizes. In lap welding, it's difficult to supervise the welding and the weld-to-wear or empty-weld may be occurred very easily for the wall thickness are noly 0.2mm both of the tubes.

Prefer configurations where the molten material of the edge of optical unit tube flowes into the surface of the splice tube, so the fillet welding is the best way relatively. In addition, the heat will transmit shorter, so it can reduce the damage to the inner fibers when welding. Therefore this method was adopt in this paper.

2.3.2 Weld energy and overlapping area

We have made a lot of trials in order to establish the optimal welding. It appeared that the right laser energy is about 1.5~3J with the temperature below 100℃ inside the tube besides the welding points tested by thermocouple. Then to further explored the optimal energy to weld the tube in the experiment. Experience suggests that the air tightness will performance well when the overlapping area of the overlapping between two welding spots is more than two-thirds of the single spot area.

3. Experimental tests

3.1 Characterization of appearance

The view of finished splicing with the optical unit tube and splice tube as shown below.

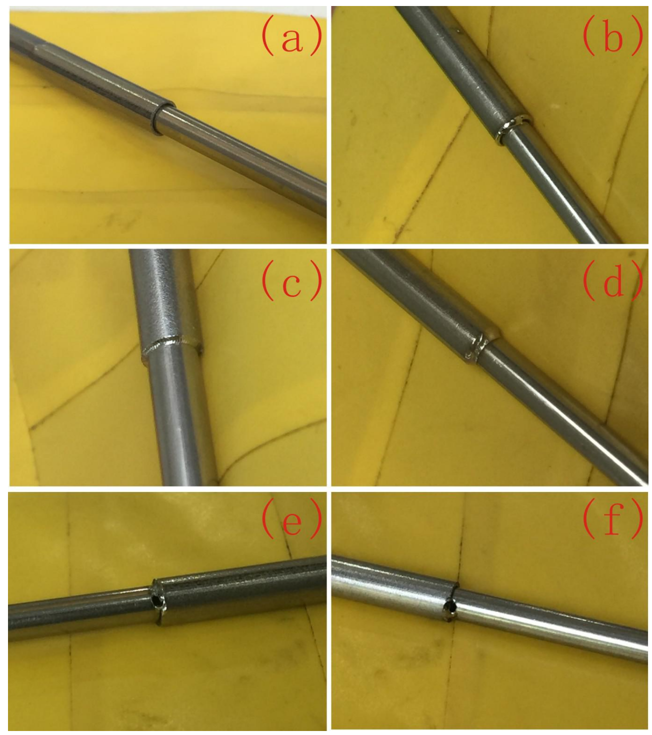


Figure 5. The appearance of splice after welding

(a)Without welding (b)In 1.66J;(c)In 1.99J; (d)In 2.23J; (e)In 2.52J;(f)In 2.66J

From the Figure 5, The appearance of picture (b) and picture (c) are very nice without any leakage solder or being welded through. But it's obviously to see there are lack of weld in picture (b) and being welded through in picture (e) and (f).

From the results, the heat absorbed by the steel tube is not enough to melt the steel of the welding spot fully when the laser energy is 1.66J, leading to the poor welding. In actual process of splicing, there are always very little residual fiber filling gel in the gap between splice tube and optical unit tube after crimping. But when laser energy is 2.52J or 2.66J which have already reach a certain degree, the fiber filling gel maybe melt to liquid and absorb a lot of heat after laser irradiation, then weld through the tube.

So we choosed the samples in 2.23J to test the air tightness and optical fiber performance, besides to add the samples in 1.66J and 1.99 J to do the tensile strength test of the splice.

3.2 Mechanical Tests of splice

The tube spliced are tensile tested in testing machine. There two sets of splice in different pulse energy were made and tensile tested. One set is pulse laser welding after crimping and the other set is pulse laser welding without crimping. Three energy levels were used when splice the optical tube in both sets and there 3 samples were used at each energy level. The test results are in the Table 3 and Table 4. The tensile strength of splice tube body is 1315.9N and the tensile strength of optical unit body is 1998.6N.

Table 3. Tensile strength in different pulse energy without crimping

Pulse Energy	The average tensile strength of splice	Comment on strength of splice tube body	Comment on strength of optical unit body
1.66J	312.4J	23.74%	15.63%
1.99J	521.7J	39.65%	26.10%
2.23J	511.3J	38.86%	25.58%

Table 4. Tensile strength in different pulse energy with crimping

Pulse Energy	The average tensile strength of splice	Comment on strength of splice tube body	Comment on strength of optical unit body
1.66J	1169.2N	88.85%	58.50%
1.99J	1258.6N	95.65%	62.97%
2.23J	1191.7N	90.56%	59.63%

From the Table 3, it show that the tensile strength without crimping is not very good and the maximum is only 39.65% of the splice tube body and 26.10% of the optical unit tube body. There May be a risk of tube fracture in the process of production. But in Table 4 the tensile strength are all excellent and even the weakest splice is more then 88.85% of the tensile strength of the splice tube body and 58.50% of the optical unit tube body.

These results show that the tensile strength of the splice with the optical unit tube and splice tube only by laser welding will be very low that may lead some risks on the subsequent process of production. If splicing by welding after crimping, the tensile strength of the splice will be strong enough to through the subsequent processing. So we need to combine two ways of laser welding and crimping to increase the tensile strength of splice as much as possible.

3.3 Air tightness test

The air tightness of the welding was tested by the Helium Leak Detected. In test, the Helium flows as a carrier gas through the test chamber and the discharge. In the case of a leak, air and thus also its natural content of argon is mixed to the helium gas-flow through the chamber. The argon content of the mixed gas flow through the discharge is determined by wavelength modulation diode laser atomic absorption spectrometry. The resulting absorption signal is a measure for the existing leak-rate.

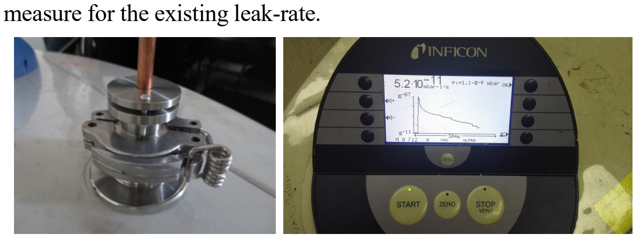


Figure 6. The appearance of splice after welding

When the detecting leakage rate curve is change to a constant, the value showed is 5.2×10^{-11}mbar • l/s. Then blow the helium around the welding points, but there almost no obviously change about the leakage rate value which can be showed that there no welding defects and good sealing performance. So the splice with laser welding can achieve a excellent air tightness which can withstand a deep water pressure.

3.4 Mechanical Tests of fibers nearby the welding points

For testing, 30 samples of each fibers were cut, each to a length of 210 cm. This allowed 50cm on each end to be wrapped on a capstan for securing in the Tensile testing machine with a free length of fiber in between of 1 meter. A free fiber length of one meter is a commonly used gauge length in fiber optic testing procedures. And make sure that the fibers besides the welding points are all located the middle of the gauge length. The fibers were tested in room temperature (27 ± 2℃) air at a relative humidity of 62 ± 2%.

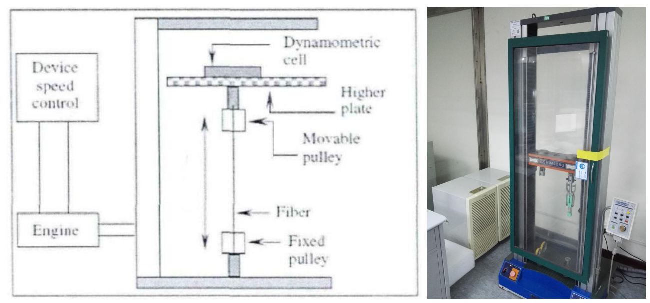


Figure 7. Schematic description of the dynamic tensile tester

Table 5. Two-point bending dynamic fatigue results

Item	X-1	X-2
Tensile strength in 15% of Weibull probability (MPa)	4329.85	4288.27
Tensile strength in 50% of Weibull probability (MPa)	4371.44	4354.32

The tensile strength of the fibers are showed in the Table 5. X-1 is the sample of the fibers beside the welding point, and X-2 is the original fibers namely without welding.

From the results, the tensile strength of two groups of fibers is very close that the difference is only 41.58 MPa in 15% of Weibull probability and 17.12 MPa in 50% of Weibull probability. The difference are very small compared with the overall strength. So the welding at 2.23J almost don't decrease the tensile strength of the fibers besides the welding points.

3.5 Dynamic fatigue testing for fibers nearby the welding points

A two-point bending equipment from fiber sigma was used to evaluate dynamic fatigue and dynamic strength by following two-point bending method, at a faceplate velocity of 1, 10, 100, 1000 μm/s, with fibers tested in room temperature (28 ± 2 ℃) air at a relative humidity of 67 ± 2%.

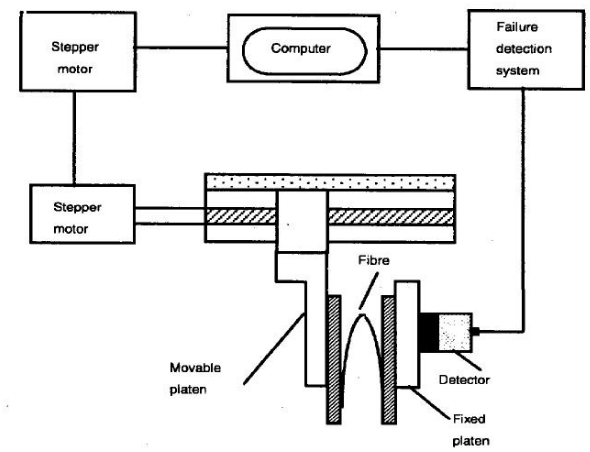


Figure 8. Schematic of the two-point bending unit

At least 15 specimen were tested at each of plate velocities of 1, 10, 100, 1000 μ m/s to decide dynamic fatigue performance.

Table 6. Two-point bending dynamic fatigue results

Fiber ID	X-1	X-2
Nd	17.78	18.05

The filuere stresses as a function of the rate of loading four different constant velocity, closely fit straight lines on the log-log plots. And then calculated the value of Nd showed in the Table 6. X-1 is the sample of the fibers beside the welding point, and X-2 is the original fibers namely without welding.

From the results, the fibers beside the welding point (X-1) performed well with the Nd of 17.78, almost the same level with the original fibers (X-2)(namely no welding) with the Nd of 18.05, which can be show that the welding at 2.23J almost have no damage to the nearby fibers about the dynamic fatigue.

4. Conclusions

According to the observations and experimental results it was concluded the following:

Pulsed Laser Welding can be used in optical unit splicing. Tests on the finished splice with the combination of the crimping and welding showed sufficient tensile strength and excellent gas tightness. The tests on the fibers besides the welding also shows excellent optical fiber tensile strength and fatigue performance, which can be show that the laser welding have no damage to the nearby fibers if the laser energy is controlled properly.

5. Acknowledgments

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6. References

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7. Pictures of Authors

Xiong Wang

Xiong Wang joined Jiangsu Hengtong marine cable sysytems Co., Ltd. in 2014 after graduation from China University of Geosciences with M.S degree in Faculty Of Materials Science And Chemistry, and has been engaged in research and development of chemical materials. He is now a R&D engineer in R&D department.

Changji Hao

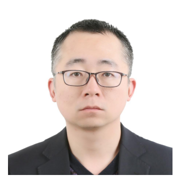
Mr Changji Hao was born in Heilongjiang Province, China, in 1987. After he graduated from Harbin University Of Science And Technology, he joined Hengtong Marin in 2010. Since then, he has been working in Engineering team.

Jiabin Chen

Mr. Jiabin Chen was born in Anhui Province, China, in 1989. After he graduated from Xidian University, he joined Jiangsu Hengtong marine cable sysytems Co., Ltd. in 2015. Since then, he has been working in the Engineering team.

Rendong Xu

Mr. Rendong Xu was born in 1969, He has been engaged in research of optical fiber and optical cable more than 20 years after his graduation from Wuhan University of Technology. He now works as general manager in Jiangsu Hengtong marine cable sysytems Co., Ltd.



Lei Zhang

Mr. Lei Zhang joined Jiangsu hengtong in 2011. He has been working in submarine cable technology area more than ten years after graduation from Harbin University of Science and Technology. Now he is the manager of R&D Department of Jiangsu Hengtong marine cable sysytems Co., Ltd..

Charles Jeremy Brown

Jeremy Brown has more than 30 years working experience in the submarine cable industry. He received Ph.D. degree in Queen's University Belfast in 1986 He focuses on the submarine optical fiber cable research and its technology and engineering. He now works as chief engineer in Jiangsu Hengtong marine cable sysytems Co., Ltd. He is in charge of technical research and production.

Shaobo Ma

Mr. Shaobo Ma was born in Shanxi Province, China, in 1986. He joined Jiangsu Hengtong marine cable sysytems Co., Ltd. in 2014. Since then, he has been working in the R&D department.

Di Wu

Mr. Di Wu was born in Jiangsu Province, China, in 1984. He has been engaged in research of optical fiber and optical cable for 10 years after his graduation. Jiangsu Hengtong marine cable sysytems Co., Ltd. in 2014. Since then, he has been working in the technology research and development department.

Bin Zhang

Mr. Zhang was born in 1989, He received his master degree in Xi'an technological university in 2014. He joined in hengtong group in 2014. Now he is an engineer in Furukawa Electric Xi'an Optical Communication Co.,Ltd. He specializes in research on optical fiber cable and new product development. He has been applied for 11 patents and published 4 papers.