# THE FEASIBILITY OF LASER WELDING IN SUBMARINE CABLE MANUFACTURE

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**Abstract:** For submarine optical cable laser welding is used for the manufacture of the steel tube housing optical fibers. However, the argon arc welding process is generally the established and qualified method of manufacturing the copper tube surrounding the strength member in the LW cable construction.
This paper investigates the feasibility of welding the copper tube with using laser technology. Laser welding equipment has been used to manufacture samples of copper tube & composite conductor allowing rules between laser focus, laser power and copper speed to be optimized. Process variables which affect the cable mechanical properties are identified and the main benefits and differences between the laser welding process and argon arc welding process to manufacture cable are summarized.
The benefits of adopting laser welding are discussed and the lessons learned from practical R&D prototype cable manufacturing are presented and discussed. This is considered to be a significant new technology for the manufacture of submarine optical cable.

Keywords: laser welding, submarine cable manufacture, copper tube.

## 1. INTRODUCTION

A cross section of modern submarine optical deep water cable is shown in Figure 1.

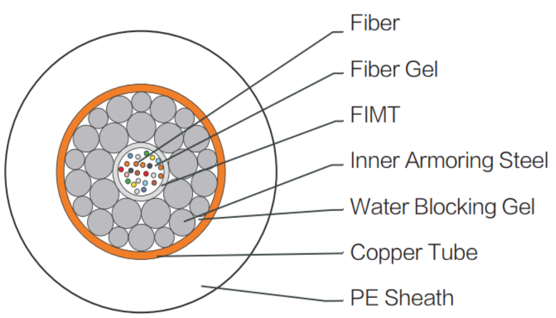



**Figure 1: LW cable cross section**

To satisfy the power requirements of modern cables used in trans-oceanic repeatered systems, the cable design incorporates a copper tube surrounding the inner steel armouring wires. During manufacture the copper tube is formed from a flat tape which is rolled into a tubular shape and welded, before being drawn down and swaged onto the underlying steel wires. The longitudinally wrapped metal tape has to be continuously welded into a tube to ensure:

(a) the steel wires are kept in the design position,
(b) the copper does not slip over the steel wires causing cable handling problems at high cable strains during deployment or recovery operations,
(c) the copper surface is smooth with no sharp edges which could cause electrical stress,
(d) the copper tube provides radial water blocking capability
(e) the copper tube provides radial hydrogen ingress protection to the cable structure.

(f) to prevent any leakage of water blocking compound during the next manufacturing process – the extrusion of the polyethylene insulation.

The requirements for a high quality continuous welding process are therefore extremely important in the manufacture of a high quality submarine cable.

In general the optical fibers in submarine cables are protected in a tube around which steel wires are wound. The cable design discussed here uses a stainless steel tube is formed from a flat tape into a C section tube and then welding the gap between the two tape edges to manufacture a closed tube. Laser welding is used during manufacture of Fiber in Steel Tube (FIST), as this is an efficient, precise and controlled welding method with high energy density[1] as heat source. The laser beam welding technology is a mature process and has been verified and improved over many years.

Copper is widely used in submarine optical cable production, due to good mechanical & electrical properties and ease of processing. The copper tube is processed in a similar way to the steel tube in the FIST production. The copper tape is trimmed to a fixed tape width and is formed into a copper C-tube before welding the two edges together to form a continuous tube. The process is combined with the inner armor cable core manufacture and after drawing down the copper tape onto the steel wires the composite conductor cable element is made. Most submarine optical cable manufacturers adopt the argon arc welding method to process the copper tube on the composite conductor line.

Laser beam welding has not been a widely used craft in copper tube composite optical cable manufacture.

## 2. SETTINGS AND ADJUSTMENT

To investigate the feasibility of laser welding for copper tube composite cable manufacture, an R&D composite cable line with laser beam welding was set up for process trials and experiments, while manufacturing standard repeatered HORC-1 cable (Figure 2).

A disc laser transmitter with a maximum power of 10KW, was used in trials. In order to avoid damage of laser transmitter because of laser reflection [2], and also to achieve a better welding effect, the angle between laser head and the copper tube line was set to a large degree.

The manufacture process of copper composite optical cable requires the welding seam to be continuous, so the process has to be controllable at all times, during the line start up, speed increases, at normal line speeds, reductions in line speed and during stopping. The laser power therefore needs to be varied according to the line speed so that a high quality welding result can be achieved. The factors which directly influence the laser beam welding quality were investigated including(a) laser focus' position, and (b) the laser power relative to (c) the copper tube speed.

For the R&D samples, red copper tape which thickness less than 1mm was used.

**Figure 2: Laser welding line**

A series of different groups of parameters were selected to weld the copper tube. The initial aim was to understand the relationship between laser focus' position and welding quality. A rough range of laser power was confirmed after several attempts, and finally appropriate power at a low speed was selected to investigate the laser focus position relative to the copper tube. Several samples were made at different laser focus settings over the range 2.11 to 3.01 (Figure 3) and the weld penetration was observed by taking tube cross section samples. The weld penetration results are shown in Figure 4. And it was decided to continue tests using a laser focus position of 2.91. With the laser focus fixed, the relationship between laser power and copper tube speed was found by using same welding seam judgement method.


**Figure 3: Laser focus rotary knob**

## 3. ANALYSIS

Thewelded copper tubes were sectioned and the cross section prepared with a polish-grinding machine, and an acid etch to show the material & weld grain structure. The welding seam results are as follows

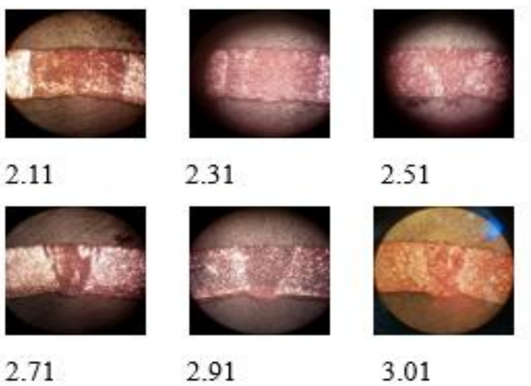



**Figure 4: laser welding sample cross section**

When observing these cross-section pictures some observations can be made. The welding seam appears very wide when laser is focused below the surface copper tube. Under these conditions, the cable elements under the copper can be at high risk of weld damage, causing a reduction in mechanical strength. When the laser focus is adjusted to a higher position, the weld seam cross section becomes sharper and an inverted triangle shape occurs [3], with the bottom of welding seam being arc-shaped.

With the laser focus position at 2.91, the penetration of copper tube met our requirement. With the laser focus fixed at 2.91 the relationship between laser power and welding speed could be investigated by comparing penetration depth and copper thickness to ensure laser welding penetration rate.

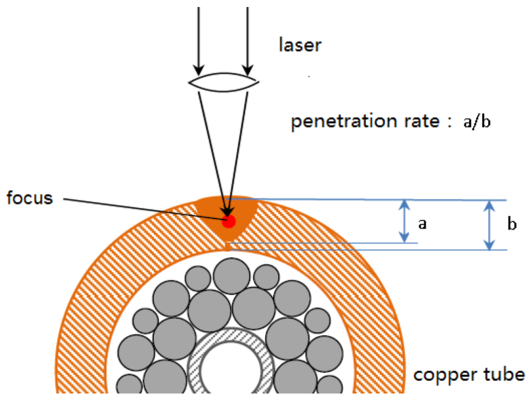
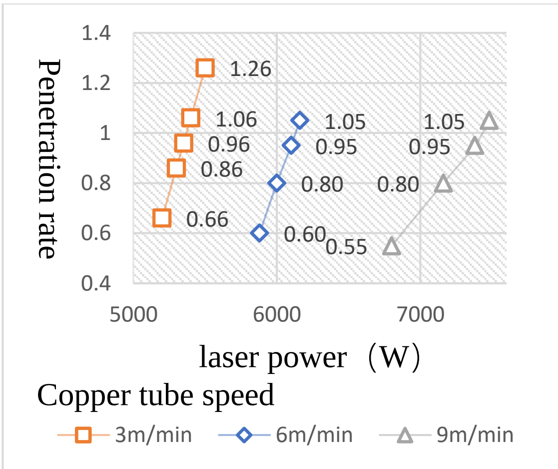


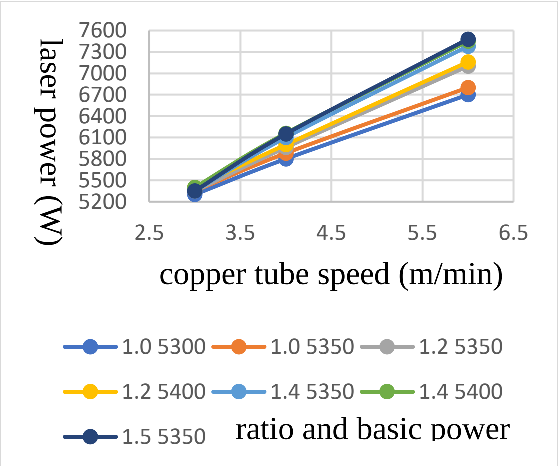

**Figure 5: Penetration rate**




**Graph 1: Penetration rate vs laser power**

The relationships between penetration rate and basic power results are fairly obvious. For the same required weld penetration, as copper tube speed is increased, so the higher the laser power needed. It is important to note that the laser power change rates are different when compared to penetration rate at different speeds.

From the results obtained the relationship between copper tube speed and laser power under different parameters can be defined. Therefore, the laser basic power can be adjusted with copper tube speed change to obtain a suitable weld penetration, and achieve a high quality weld.




**Graph 2: Laser power vs copper tube speed**

From the measured laser power and copper tube speed (different weld penetration ratio and laser basic power), optimum process conditions can be defined. The welding parameters selected to produce stable, high quality welds used the following settings: at a copper welding speed of 3m/min the laser basic power required was 5400W and penetration ratio was 1.2

## 4. TESTS

The strength of the weld seam mainly affects the mechanical performance of cable, so several tests were devised to check the cable mechanical properties.

Repeated twisting

Repeated twisting of the cable along the cable axis, over a distance of 150mm and applying a rotation of +/- 180 degrees and hold for 5 minutes. At least 6 cycles were completed to check the weld quality and examine for any signs of cracking.

Over 30 weld samples (prepared using a range of suitable parameters) were tested with the results showing no cracks or other weld defects.

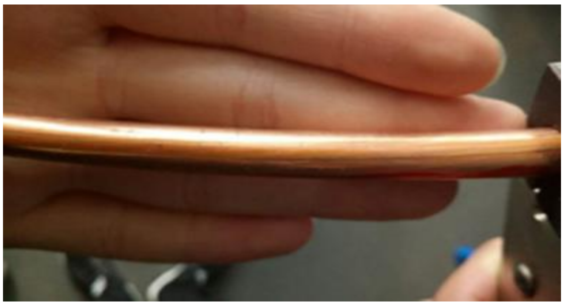


**Figure 6: Twist test result**

Bending and wrap test.

To verify the ability of the weld in bend the composite conductor was subjected to a 10 times diameter wrap test involving 3 full 360 degree wraps and hold for 5 minutes.

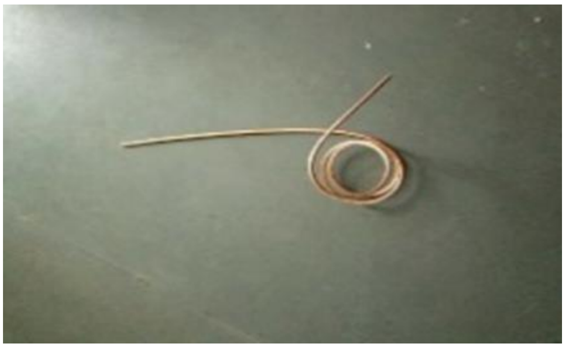


**Figure 7: Bending wrap test**

Over 30 weld samples (prepared using a range of suitable parameters) were tested with the results showing no cracks or other weld defects.

**Figure 8. Bending wrap test result**

Crush & Impact resistance test

To verify the weld crush resistance of LW cable, samples were prepared using both laser welding and argon arc welding of the composite conductor. The samples were subjected to the same crush load of 50kN force applied between 2 flat 100mm length plates with the load applied for 10 minutes. After testing the HDPE insulation was removed and the weld seam inspected along the crush zone. Both laser beam welding samples and argon arc welding samples showed no defects.

| Sample number | Laser beam welding | Argon arc welding |
|---|---|---|
| Sample 1 | No crack | No crack |
| Sample 2 | No crack | No crack |
| Sample 3 | No crack | No crack |

**Table 1: Crush test comparation**

To verify the impact resistance of LW cable a suitable 10kg weight was dropped from a range of heights onto LW cable. The position of weld seam relative to the impact point was controlled and tests were completed with the weld seam at Top Dead Center (TDC) and rotated by 90 degrees. Test results are shown in Table 2. With the laser weld seam at TDC upwards both the laser weld and argon arc welded composite conductor could withstand 100J impact energy with no weld defects or cracking. With the weld seam orientated at 90 degrees, the laser weld seam could withstand 80J energy while the argon arc welded sample was slightly higher at 90J impact energy, without any weld defects or cracking.

| Sample | Laser welding | Argon arc welding |
|---|---|---|
| Weld Seam at TDC | 100J | 100J |
| Weld Seam At 90 degrees | 80J | 90J |

**Table 2. Impact test comparation**

## 5. DISCUSSION

A visual comparison of the laser welded and the argon arc welded composite conductor reveals that the width of laser welding seam is much smaller than the width of argon arc welding seam, and the heat-affected zone of laser welding seam is smaller than that of argon arc welding.

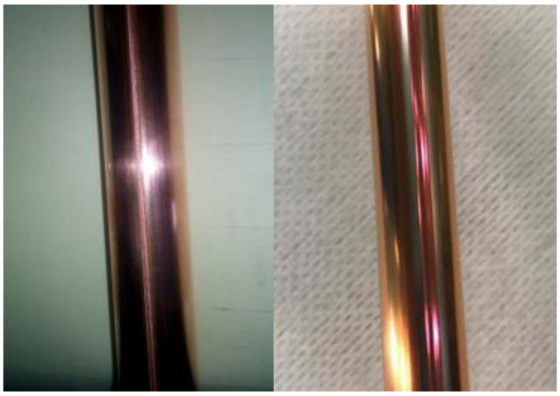


**Figure 9: Comparison of welding process (laser weld to left, argon arc weld to right)**

The Laser beam weld energy density is more concentrated than argon arc welding, so laser beam welding can be more efficient. The laser welding process is more tolerant of copper impurities and so lower grades of copper can be welded using this technique, whereas only the highest grades of copper can be welded in long lengths using the argon arc welding process. The argon arc welding process is length restricted due to the build-up of impurities on the tungsten needle welding electrode, which must be periodically changed. Thus, the use of laser beam welding can result in longer lengths of continuous welding compared to the present argon arc welding process where the tungsten needle electrode needs to be replaced periodically and involves stopping and restarting the line. The laser process can therefore improve production efficiency.

The Argon arc welding method uses the electric arc to produce energy and melt the copper. As the copper is utilised as one of the electrodes, the copper surface needs to be clean enough so that arc can be made and sustained. On the other hand, laser beam welding energy is focused near the copper, so the welding results are not as sensitive to or affected by the cleanliness of the copper tube surface. Indeed, some small areas of contamination on the copper surface can be fired& cleaned by the laser, which is another growth application for laser technology, namely the cleaning of metal surfaces.

When considering the high output laser power required to weld the copper tube it may be possible to cause defects to materials below the weld point[4], and if present the defects could be more severe than those caused by an improper argon arc welding. To avoid causing defects to material under the weld point, the laser beam welding requires greater precision control than argon arc welding. Factors to be considered include line vibration, declination of open copper tube gap, homogeneous raw material, stable laser power modulation [5] ,wavelength [6] ,and a stable copper tube forming method/welding settings [7]etc.

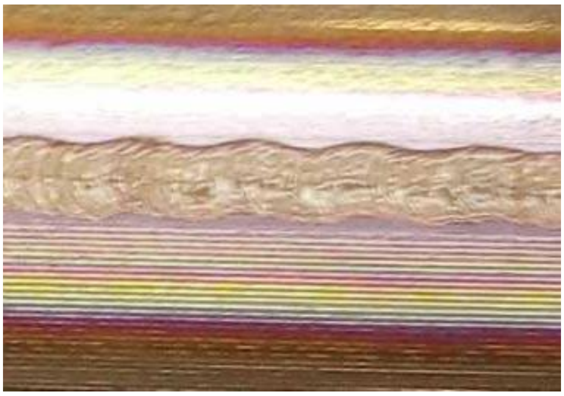


**Figure 10: Laser weld seam with vibration**

The good thermal conductivity of copper causes the efficiency of laser beam welding energy utilisation to be low during manufacturing. As only part of the laser energy is used, the remaining energy is dissipated through reflection from the tube surface and internal conduction. To improve the energy utilization, measures can be taken, such as the surface treatment to improve the laser energy absorption rate[3].

## 6. CONCLUSIONS

- This work has shown that the use of laser welding in the manufacture of copper composite submarine optical cables feasible and can produce an acceptable high quality weld over long continuous lengths.
- Laser welding of copper could enhance productivity compare to argon arc welding because there is no requirement to change the tungsten needle.
- The mechanical strength of the cable is equivalent to that of the argon arc welding process and provides acceptable cable properties and characteristics.
- However, defects caused by laser welding are severe. Good control of the laser focus position is required together with variable laser power to match the copper tube line speed.
- Some additional measures are required to stabilize the forming, &welding

process, ensuring continuous long length production.

- Submarine optical cable has been produced on a pilot run using laser beam welding technology, with no major issues to report.
- The use of laser beam welding is considered to be a significant new technology which allows lower surface cleanliness copper to be processed with corresponding cost savings.

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