CLASS GUIDELINE

DNVGL-CG-0287 Edition December 2015

Hybrid laser-arc welding
FOREWORD

DNV GL class guidelines contain methods, technical requirements, principles and acceptance criteria related to classed objects as referred to from the rules.

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This is a new document.
CONTENTS

Changes – current............................................................................................................. 3

Section 1 Introduction...................................................................................................... 6
  1 Objective.................................................................................................................... 6
  2 Background.............................................................................................................. 6

Section 2 The hybrid laser-arc welding process............................................................. 7
  1 Description of process.............................................................................................. 7
  2 Particulars of the hybrid laser-arc welding process.............................................. 8
  3 The Society’s approval strategy.............................................................................. 8

Section 3 Base material.................................................................................................. 9
  1 General.................................................................................................................... 9

Section 4 Test requirements applied to hybrid laser-arc welds..................................... 10
  1 Welding consumables.............................................................................................. 10
  2 Welding personnel.................................................................................................. 10
  3 Welding process approval...................................................................................... 10
  4 Preliminary welding procedure specification (pWPS).......................................... 10
  5 Welding procedure tests....................................................................................... 10
  6 Surface condition.................................................................................................. 12
  7 Tack welding.......................................................................................................... 12
  8 Repairs.................................................................................................................. 12
  9 Fatigue testing........................................................................................................ 12

Section 5 Monitoring of the hybrid laser-arc welding machines.................................. 13
  1 General.................................................................................................................. 13
  2 Maintenance and checks of the conventional equipment..................................... 13
  3 Checks and measurement of the laser beam properties....................................... 13
  4 Control of welding parameters.......................................................................... 13
  5 Welding production test (WPT)............................................................................. 13

Section 6 Protection against laser radiation hazards................................................... 15
  1 General.................................................................................................................. 15

Section 7 References..................................................................................................... 16
  1 List of references.................................................................................................. 16
SECTION 1 INTRODUCTION

1 Objective
This document contains the Society’s guidelines for the qualification and approval of hybrid laser-arc welding. They form the basis for accepting the use of laser-arc hybrid welding in construction of vessels classed to the Society.

2 Background
Traditionally, shipyards have mainly used manual welding, mechanised flux cored arc (FCAW) welding and submerged arc welding in the production of ships. However, until recently use of these conventional welding techniques in welding of thin plates typically applied in decks of cruise ships, often resulted in deformations which required a large extent of straightening, adjustment and fitting operations. In order to overcome these problems, laser beam welding has been an attractive option because of its low heat input typically in the range of 0.2 - 0.3 kJ/mm. Many yards have performed welding trials and small scale production using laser processing.

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In a large scale, however, hybrid CO₂ laser-arc welding has been used only by a limited number of shipyards building cruise ships.

Hybrid laser-arc welding is a combination of a laser beam and a conventional arc welding process. As described below this combination allows to exploit the benefits of both welding techniques to significantly decrease heat distortion and increase productivity.
SECTION 2 THE HYBRID LASER-ARC WELDING PROCESS

1 Description of process

The combination of laser and arc welding techniques is called hybrid laser-arc welding, a descriptive term that includes the laser type (i.e. CO$_2$, Nd: YAG) and the arc welding process (MIG/MAG, TIG). Hybrid laser-arc welding is a process in which the laser beam and the arc are combined in one process zone and form one joint melt pool – see Figure 1.

![Figure 1 Principle sketch of the hybrid laser-arc welding process](image)

The laser beam stabilizes the arc and contributes to the typical deep penetration effect and high welding speed of the hybrid process. This leads to an increased productivity and improved accuracy of the pre-assembled structures.

The arc welding process makes it possible to produce high quality welds with larger gaps than a laser beam process. Moreover, it reduces the cooling rate of the weld zone which leads to improved mechanical properties of the joint.

The practical consequence is that laser beam processes require steel specifications different from those commonly used in shipbuilding today. Hybrid laser-arc processes, however, can be applied to conventional shipbuilding steels.

To summarise one can say that the synergistic actions of the laser and the arc are exploited, improving the welding efficiency compared with the individual processes.
2 Particulars of the hybrid laser-arc welding process

Hybrid laser-arc welding gives smaller heat input, and hence smaller welding zones, than conventional welding processes. A few special features therefore apply to this kind of welding:

— The narrow welding zone puts stricter requirements to geometrical tolerances. Strict control of all geometrical tolerances for materials to be welded, therefore, is necessary.

— Similar, strict requirements must be set to the positioning of the welding equipment. Experience has shown that a likely type of weld defect is that the welding arc fails to hit the groove, so that the groove remains (wholly or partly) as a large defect. For this reason, only full penetration welds, where correct positioning of the weld can be verified by visual inspection of the root side, is acceptable.

— To correctly position the weld, the welding device is equipped with a “seeing eye” or a “seam tracker”, to know exactly the position of the groove. These devices are sensitive to changes of surface properties (light reflection of surface).

— The hybrid laser-arc weld solidifies faster than conventional welds. For this reason, welding on shop primed surfaces is usually not possible for hybrid welding processes.

3 The Society’s approval strategy

Concerning laser beam welding in shipbuilding, a set of guidelines was produced in 1996. These Guidelines for the Approval of CO₂ – Laser Welding were a result of a joint European effort between shipyards, steelworks, institutes and classification societies. However, relatively strict requirements were put on steel composition, non-destructive testing and weld tolerances resulting in more expensive materials and extensive quality control. After the first set of unified guidelines was issued, work has continued to be performed in order to simplify the mentioned procedures.

The following approval strategy is used by the Society for hybrid laser-arc welding, independently from the above mentioned guidelines for laser beam welding.

As the first step, the essential process parameters, along with their tolerance windows, must be defined. This takes sets of systematic trials and tests, and results in definitions of the target welding parameters to be used, their influence on the properties of the weld and their acceptable variation during practical welding. Multi-dimensional statistical modelling has proved to be a powerful tool to handle this task.

The second step is to implement the results into practical welding. A stable and repeatable welding process must be achieved. When a novel welding process is introduced in a workshop, there is by experience always a “trial and error phase” before the process becomes stable and repeatable. Formal class approval work should not start in this turbulent phase, but wait until the process is under control, and can be demonstrated to be stable and repeatable.

When a stable and tolerant welding process is established and demonstrated, it is time to proceed with formal class approval, comprising establishment of a pWPS (see Sec. 4 [4]) and WPQT (see Sec. 4 [5]). These steps follow the same strategy as described in the Society’s rules for conventional welding processes. In the pWPS, several new parameters must be defined to reflect the particularities of the hybrid laser-arc welding, but the principle is still the same as for conventional welds. In the WPQT, generally the same tests as for conventional welds are required, for details see Sec.4.

The last step is the running-in of the process in actual production welding. In this phase, class attention and amount of testing should be higher than that used for conventional welding. As confidence and experience is gained, the amount of testing should gradually be reduced to the normal level for testing of conventional welds.
SECTION 3 BASE MATERIAL

1 General

No special restrictions with regard to chemical composition and material properties are required for using the hybrid laser-arc welding process compared to conventional arc welding processes. Ordinary hull structural steel grades according to the Society's rules for classification RU Ship Pt. 2 up to and including VL E36 have been used with good results.

Steel material thickness welded with the hybrid laser-arc welding process have typically been used and approved as follow:

- **Butt welds**: min. 4 mm, max. 30 mm (multi-layer);
  standard 5-12 mm,

- **Fillet welds**: min. 4 mm, max. 15 mm;
  standard 6-12 mm
SECTION 4 TEST REQUIREMENTS APPLIED TO HYBRID LASER-ARC WELDS

1 Welding consumables
Welding consumables and auxiliary materials such as gases and fluxes, should be defined in the pWPS. As for all welding on classed objects only welding consumables and auxiliary materials type approved by the Society should be used.

2 Welding personnel
Machine operators should receive adequate training given by personnel having the special knowledge to do so. The training should enable the operators to set-up, programme and operate the machines adequately. Basic knowledge about the particularities of hybrid laser-arc welding and how to establish and follow a welding procedure specification should be included in the training.

3 Welding process approval
Before welding procedure approval can be started, it must be demonstrated that a stable and repeatable welding process is developed. Further, it must be documented that all welding parameters used are defined in such a way that foreseeable variations during fabrication welding does not lead to unacceptable quality of the welds. This is an important part of the Society's approval strategy, as explained in Sec.2 [3].

4 Preliminary welding procedure specification (pWPS)
For welding of the test assembly a pWPS should be established. The pWPS should be prepared in accordance with ISO 15609-6.

5 Welding procedure tests
5.1 General
The welding and testing of test pieces should be in accordance with [5.2] and [5.3] to [5.4] respectively.

5.2 Test piece
Test pieces should be prepared in accordance with relevant parts of ISO 15614-14 paragraph 6.

5.3 Non-destructive testing (NDT)
NDT should be carried out to an extent as follows:
— 100% visual testing
— 100% radiographic- or ultrasonic testing (full penetration T-joints above 10 mm: ultrasonic testing), and
— 100% surface crack detection (magnetic particle- or dye penetrant testing).
The classification levels and acceptance criteria used for conventional butt- and fillet welds are given in ISO 5817 level B unless otherwise specified.
The visual examination should put special attention to correct penetration, absence from pores and impurities and absence from unfavourable weld profiles.

5.4 Destructive tests
For butt welds the following tests are relevant:

- tensile test
- bend test
- Charpy V-notch test
- macro section test
- hardness measurements.

Number of tests and the test results should be in compliance with the Society’s rules except that only 3 sets of Charpy V-notch specimens are required. (Location FL+5 mm can be omitted). The bend tests are very important in this respect since this particular welding process could produce defects that are difficult to detect by conventional NDT methods but are easily picked up by bend testing.

On the macro section, sharp transitions may occur. If in doubt, the fatigue effect of such geometries must be tested during the qualification. Experience has shown, however, that even quite unfavourable weld profiles on the root side do not impair the fatigue properties of a hybrid laser-arc weld compared to a conventional weld.

In any case, the approved macro section must be used as reference for acceptable geometries of production welds during visual inspection.

Concerning hardness requirements, values less than or equal to 380 HV5 are considered acceptable for in-house automatic production lines. This increase has been justified due to:

- use of extra low hydrogen (H5) welding consumables
- the welding process is stable and computer controlled
- pre-machined grooves and fixed jigs securing stable groove geometry.

For conventional outdoor welding procedures, 350 HV5 should be applied.

For fillet welds the following tests are relevant:

- macro section test
- hardness measurements.

Re-testing should be in compliance with the Society's rules.

### 5.5 Range of approval - essential variables

The following changes should lead to a new qualification:

- any change in consumables
- any change in base materials
- any change in welding position
- any major change of surface condition
- any change of joint geometry versus that specified in the welding procedure qualification record (WPQR)
- any change outside thickness range 0.8t to t (where t is WPQT thickness)
- any change of edge preparation
- any change in focus length and position
- any change in laser machine
- any change in heat input outside the range ±15%.

Range of approval related to other variables may be taken according to established practice as given in recognised national and international standards.

### 5.6 Welding procedure qualification record (WPQR)

The WPQR is a statement of the results of assessing each test piece including re-tests. The relevant items listed for the WPS in ISO 15609-6 shall be included together with details of any features that would be rejectable by the requirements of [5.4]. If no rejectable features or unacceptable test results are found, a
WPQR detailing the welding procedure test piece results is qualified and should be signed and dated by the surveyor.

A WPQR template should be used to record details for the welding procedure and the test results in order to facilitate uniform presentation and assessment of the data.

An example of a WPQR template is shown in Appendix A.

**6 Surface condition**

Concerning fillet welds, the shop primer should be removed from the flange surface in order to avoid pores and spatters making the welding process unstable.

**7 Tack welding**

Hybrid laser-arc welds may require special procedures for tack welding. Tack welding by laser beam welding is often used, in order to make the tack so small that it does not disturb the subsequent welding. The same rule as for other tack welds apply: If the tack remains a part of the finished weld, the tack welding procedure must be qualified and approved.

**8 Repairs**

Defective welds i.e. welds which do not fulfil class requirements, can be repaired by conventional welding methods according to class requirements. In order to ensure quality, the following measures should be carried out:

- examination of welds using the methods described herein
- marking of defective section of the weld
- grinding of defective section
- conventional repair weld
- check of the repaired section by NDT.

**9 Fatigue testing**

Fatigue testing is not required as part of conventional WPQTs, provided the welding method and equipment is known from former use or qualifications elsewhere. Fatigue performance of conventional fusion welds is defined for different structural details, and included in standards used for dimensioning. For novel welding processes, therefore, it must be secured that the fatigue performance of the welds is at least as good as that reflected in the design curves.

Practically, this has been performed for hybrid laser-arc welds by testing specimens with relevant geometries – butt welds and fillet welds – and plotting the data along with the known/recognised design curves. If the data points are clearly above the design curve, it is concluded that the fatigue performance of the joint is acceptable.
**SECTION 5 MONITORING OF THE HYBRID LASER-ARC WELDING MACHINES**

**1 General**
A constant good condition of the machines is an essential pre-condition for an acceptable weld quality. Continuous checks of the main systems are therefore considered necessary. This applies to the mechanical parts and conventional equipment as well as to laser related systems.

**2 Maintenance and checks of the conventional equipment**
Mechanical parts like clamping systems, positioning systems, milling head etc. should be regularly checked and maintained according to specifications from the machine suppliers. The seam tracking system is essential for correct positioning of the welding head, and must be adequately maintained. Particular attention should be paid to arrangements for keeping the sensor clean.

The conventional welding equipment should also be checked regularly and preventive maintenance should be carried out according to the specifications of the supplier and common shipbuilding practice.

**3 Checks and measurement of the laser beam properties**
In order to obtain an acceptable and reliable hybrid welding process, the properties of the laser beam should be kept within defined limits.

Characteristic laser beam parameters should be measured periodically using specified equipment. The data obtained should be stored in a database and should support both the operator to adjust the process and the surveyor. While the detailed values to be kept will be part of the WPS, the main properties of the laser beam to be monitored are as follows:

— beam diameter
— laser power and power distribution
— temperature of optical elements and/or welding head
— focal length
— location of focus point
— additional measurements and checks.

**4 Control of welding parameters**
All welding parameters should be stored in a data base and transferred automatically to the machine control. The pre-set parameters are depending on the weld configuration (thickness, seam preparation, gap etc.) and should be described in the WPS. This concept will assure that correct pre-set welding parameters are used for an individual joint configuration and material. Potential weld defects can also in this way be traced back to the parameters used.

If one or more of the parameters are approaching the pre-set limits, a warning will be shown to the operator. He can then adjust or service the relevant parts of the machine. If the welding parameters reach or exceed the limits, the welding process will automatically be stopped by the control unit.

**5 Welding production test (WPT)**
Welding production tests should be carried out on the hybrid laser-arc welds. The following tests should be performed:

— visual examination
— radiographic testing
— tensile testing
— hardness measurements.
— macro section test.

Weekly checks should be used as a standard procedure in production of hybrid laser-arc welds under steady-state operations.

The results from these tests should be stored in a data base for further evaluation. The results should also be made available to the surveyor upon request.
SECTION 6 PROTECTION AGAINST LASER RADIATION HAZARDS

1 General

In general, humans shall under no circumstances be exposed to laser radiation exceeding the maximum permissible exposure (MPE) limits. The EN 60825-1 standard (5) specifies MPE values which represent the maximum level of laser radiation to which the eye or skin can be exposed without injury. In case of a potential risk of exposure to a person’s eyes above the MPE level, safety goggles shall be used. The testing, labelling and recommended choice of safety goggles for laser processing in production and laser service purposes are given in internationally recognised standards like EN 207 (6) and EN 208 (7).

Generally, Nd: YAG lasers are potentially more harmful to the human eye than e.g. CO₂ lasers.

As a simplified rule, the following can be used: All personnel in locations and positions where they can see the laser welding station or the related light, shall wear goggles adequate for that particular laser at all times.
SECTION 7 REFERENCES

1 List of references

/2/ DNV GL rules for Classification of Ships RU SHIP Pt.2 Ch.2 Sec.2 *Rolled steel for structural application.*
/3/ DNV GL rules for Classification of Ships RU SHIP Pt.2 Ch.4 Sec.5 *Welding procedures.*
/5/ EN 207:1998 *Personal eye-protection – Filters and eye-protectors against laser radiation (laser eye-protectors).*
/6/ EN 208:1999 *Personal eye-protection – Eye-protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors).*
### APPENDIX A EXAMPLE WPQR

An example of a WPQR template is shown below, partly filled in.

| WPS identification: |  |
| Manufacturer: |  |
| WPQR №: |  |

#### Equipment identification:

- Welding machine (device):
- Fibre core diameter: 0.6 mm
- Beam focussing system
  - collimating optics: 200 mm
  - focussing optics: 200 mm
- Welding power source:
- Laser power source:

#### Parent material specification:

| material 1: | web: VL A |
| thickness | 5 mm |
| material 2: | flange: VL A |
| thickness | 4 - 30 mm |

#### Filler or additional material:

- designation:
- dimensions:

#### Joint type:

- T-joint, one side welded

#### Joint design

- Geometry
Hybrid laser-arc welding

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### Preparation:

*T-joint, 0 - 0.5 mm gap in the root*

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Tacking by manually positioned Laser Tack Welder (automatic welding)

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