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Technology of Welding Large-Sized Rings of *Offshore* Structures

Abstract: The article presents practically proven technology for making single large-sized rings used in offshore structures and made of high strength steel rectangular segments (100 mm x 120 mm). The study also presents formal and documentation-related requirements as well as issues concerning quality assurance.

Keywords: welding requirements, offshore structures, large-sized rings

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Introduction

Some offshore structures contain rings having a diameter between 3 and 4 m, made of a shape having a rectangular cross-section (100 × 120 mm). At the same time, shapes of such cross-sections are present in sections being between 2 and 3 m in length. This means that the necessity of making a ring welded of several sections poses a challenge for the manufacturer as a finished product must satisfy restrictive quality requirements, i.e. a weld representing quality level B according to EN ISO 5817 and minimum shape and dimension deviations – processing allowances usually amount to several millimetres per a side.

This study presents a practically proven technology for making such single large-sized rings of six, previously formed segments and enabling the making of all welds in one fixing of the object, i.e. in the shortest possible time.

Ring material

The rings focused on in the study were made of high strength hull steel EH36+Z of sub-group 1.2, subjected to an impact strength test performed at -40°C, supplied in a normalised state, subjected to thermo-mechanical control processing, of guaranteed mechanical properties in the direction perpendicular to the product surface (quality level Z according to EN 10164) and

Table 1. Chemical composition and mechanical properties of hull steel EH36 [1]

Chemical composition, %								
C_{max}	Mn	Si_{max}	P	S	Al	Nb*	V*	Ti
0.18	0.9÷1.6	0.50	≤0.040	≤0.040	≥0.015	0.02÷0.05	0.05÷0.10	≤0.02

Chemical composition, % (cont.)				Mechanical properties			
Cu	Cr	Ni	Mo	R_e, MPa	R_m, MPa	A, %	KV, J (-40°C)
≤0.35	≤0.20	≤0.40	≤0.08	≥355	490÷620	≥21	≥34

*) Nb + V max 0.12%

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provided with an approval by a classification society [1]. The chemical composition and mechanical properties of the steel are presented in Table 1.

Formal requirements

The manufacturer of rings must satisfy the following formal requirements:

- be in possession of a qualified welding procedure, in theory, according to any offshore standard and, in practise, according to a standard referred to in the technical documentation of design/structure, authorised by a classification society being a member of the International Association of Classification Societies (IACS), with a scope including all parameters related to the welding of a ring;
- employ a welding engineer holding an EWE/IWE diploma or provide such welding coordination (personnel with entire technical knowledge according to EN ISO 14731) on other conditions. In addition to performing a welding coordination function, such an engineer should provide necessary technological documentation discussed below;
- pass an audit by the customer (ordering party) and a classification society coordinating the process of ring manufacture – demonstrating that the possessed equipment and technical level ensure the performance of such tasks satisfying the required quality level and meeting the required deadline;
- be prepared technically and organizationally regarding the recording of all welding process parameters and welds. This issue was discussed in detail in the publication [2].

In the case under discussion, the manufacturer was in possession of a welding procedure qualified according to standard DNV-OS-C401 [3], issued and authorised by the DNV (Det Norske Veritas) classification society. The scope of qualification included, among other things, the category and thickness of the ring base material as well as welding positions and methods 138/136 (penetration 138, filling 136). The qualification procedure was discussed in detail in publication [4].

After the successful manufacture of the first ring, the manufacturer started to receive subsequent orders for a few rings per annum, usually with the entire welded structure for the ring, and sometimes also only for the rings.

Documentation

Documentation (required) related to the manufacture of a ring (in fact, of each structure of this class) can be divided into the following four groups:

- design (also referred to as classification),
- technical (also referred to as workshop),
- technological,
- hand-over.

Design documentation is provided by the customer. This documentation defines the structure without execution-related details and usually contains dimensions of the finished product, quality-related requirements, formal requirements to be satisfied by the contractor as well as the structural materials and types of inspection documents according to EN 10204 (conformity certificates etc.), but without dimensional division, including lengths (and amounts) of ring bar sections and processing allowances. This form of documentation is approved by a classification society, if need be. As regards the rings, technical (workshop) documentation is detailed design documentation containing actual dimensions of the flat bar used, division into sections (number and lengths of sections) as well as the mounting diameter including necessary allowances and bevel geometry.

Technological documentation includes Welding Procedure Specifications (WPS) developed on the basis of authorised Welding Procedure Qualification Reports (WPQR) and a detailed Welding Procedure Specification, containing assumptions related to fitting and welding fixtures and important hints including the manner of assembly fixing of the flat segments with one another and with the saddle, the fixing of run-on and run-off plates etc. As regards single unit manufacture, on the assembly-welding station, the fixing is performed first and followed by the welding of a given structure or its unit. Where an order is for more pieces (even two), it is more convenient to divide the functions of both stations into assembly and welding. Such an approach reduces order processing time as it enables the fixing of the second units while the first one is being welded. As regards additional requirements formulated by a classification society, technological documentation is extended accordingly (particularly in cases of prototypes). Technological documentation is developed by the welding engineer or the team working under their supervision. In the welding scope (usually WPSs), technological documentation is usually subjected to agreement with the classification society coordinating a given project.

Hand-over documentation is to be enclosed to a finished product and should include the following documents:

– conformity certificates of structural materials – ring segments;
– conformity certificates of filler metals used (conformity certificates issued by the manufacturer and approval certificates issued by a classification society);
– list of identification numbers of filler metals (recommended, even if not initially required);
– list of welding parameter records (for each weld), usually in the version as in WPQR [2], if needed;
– copies of WPSs and corresponding WPQRs;
– list of ring-making welders along with their licences, sometimes with assigned weld numbers;
– welder certificates (copies) – formally, these should be certificates issued by maritime classification societies being members of the IACS (such a requirement is formulated in regulations of all the classifications societies). In practice, approved certificates also include those issued by Instytut Spawalnictwa, DVS, SLV, TÜV and UDT, yet they should be previously agreed with the inspector;
– reports of final non-destructive tests (NDT), where such tests must be performed by a laboratory approved by a related classification society (regardless of certificates of personnel performing tests);
– sheets containing measurements of dimensions of a finished ring and roughness of processed surfaces;
– acceptance certificate issued by a classification society on the basis of the data described above.

Pre-weld preparations

Pre-weld preparations include the following technological operations:

– bending flat bar sections into segments of a required radius;
– cutting the segments to an appropriate length, forming an X-shaped weld groove (Fig. 1) by means of mechanical bevelling of side surfaces (welding is performed in a vertical position, providing two-sided access in one fixing);
– cleaning surfaces adjacent to a weld grove to pure metal, done in order to prevent the emission of gases coming from impurities during welding;
– careful fixing of the whole before welding on an assembly stand (Fig. 2) or assembly-welding stand (bed) and making the entirety stiff in order to prevent movements of elements in relation to each other and in relation to the bed and to limit welding strains. The stiffening can be mechanical (separable), by means of technological welds (inseparable) or mixed. Assembly welds should be made after local preheating to 60°-70°C.
– fixing run-on and run-off plates (Fig. 3) and round ceramic strips. Welding performed using such strips significantly reduces the processing of the weld root, until check whitening using end mills, significantly reducing the duration of this operation.

Welding station

Assembling a ring of segments, welding them together and cooling to an ambient temperature should take place on an especially prepared technological stand (bed). As mentioned before, two solutions are possible, i.e. one universal assembly-welding stand or two separate stands, i.e. dedicated only to assembly (Fig. 2) and welding (Fig. 3-5). An assembly stand should enable the precise and comfortable assembly of ring segments into an entirety, whereas welding and assembly-welding stands should enable or be characterised by the following:

- be sufficiently rigid to prevent deformations of a ring during welding (and cooling);
- provide the effective (separable/inseparable) fixing of segments to the bed;
- enable the control of a ring shape during assembly and welding;
- provide convenient two-sided access to all welds for all technological operations, i.e. preheating, welding, grinding and inspection;
- be ergonomic, i.e. provide convenient positions during welding and other technological operations.

Welding

Welding a joint with X preparation (see Fig. 1) is to be performed in a vertical up position (PF) using methods 138/136 – penetration is to be performed on a round ceramic strip using a metallic flux-cored wire grade MC-RS, whereas filling layers are to be made using a basic flux-cored wire grade SF-36EA (both manufactured by Nittetsu) having a diameter of 1.2 mm. Pre-heating temperature should amount to 100°C, whereas interpass temperature should be 120°C. Welding current-voltage parameters are to be the following: penetration 100-120A/18-20V and filling 170-210A/22-23V. Following standard DNV-OS-C401 [3], production welding parameters specified in a WPS should coincide with parameters of an appropriate WPQR, with a permissible deviation of ± 10%. Welding is to be performed in three stages (see Fig. 1):

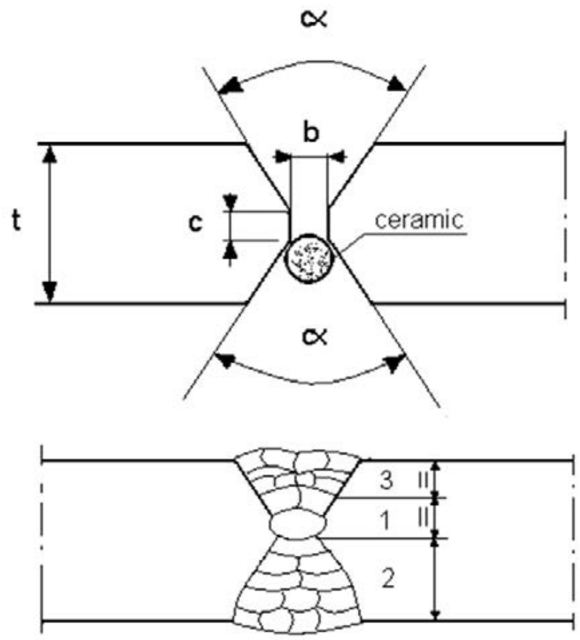

Fig. 1. Predesign of a joint and welding diagram: b=5÷7 mm; c=3±1 mm; t=100÷120 mm; α=50±5°; 1, 2, 3 – welding sequence

Fig. 2. Assembled and clamp-stiffened ring on an assembly stand

Fig. 3. Ring mounted on a welding station with run-on and run-off plates

Fig. 4. Joint during welding

Fig. 5. Weld face from the internal side of a ring (also visible a clamp fixing the ring to the bed)

- stage 1: filling 50% of a joint thickness of one side of a joint (on the penetration side),
- stage 2: entire filling of the other side of a joint (on the root side),
- stage 3: finishing a weld on one (the first) side.

This practically proven technology minimises angular shrinkage.

In cases of single-access welding (in a given position of the structure), it is more convenient to apply asymmetric X-shaped bevelling (⅓t by ⅔t). Such a solution reduces the rotation of the structure from two times to one. In the first stage, entire welding of the smaller side is performed (⅓t). After cooling to ambient temperature, the structure is rotated and the entire welding of the other side is performed (⅔t).

Classification societies require that the maximum width of a run should amount to between 12 and 14 mm, as it reduces angular shrinkage. Therefore, wider layers are to be made as multi-run (Fig. 4 and 5). Prior to each next beading, the previous weld is to be ground to pure metal and filings should be meticulously removed. Grinding is performed by fitters, while welders weld the appropriate joints.

As regards organisation, welding is to be performed by two welders working at the same time, interchangeably, each on two neighbouring joints. Two joints are to be welded, whilst two others are being ground (and cooling at the time). After the completion of welding (interchangeable or final), joints should undergo cooling being covered with a heat-insulating cover used in order to slow down a cooling rate. The ring is to be fixed to the technological stand until it has cooled entirely, i.e. until ambient temperature has been reached.

Quality control and tests

Quality control includes all the three phases of the technological process and is performed before, during and after welding. The most important quality control-related objectives are the following:

1. before welding:
- checking the correct positioning on the technological bed, the precision of fixing and the correctness of ring shape;
- checking the geometry and dimensions of weld grooves for compatibility with the related WPS as well as checking the surface purity, the fixing of ceramic strips and the fixing of run-on and run-off plates;
- checking the technical condition of semi-automatic welding machines prepared for welding, checking the connection of earth conductors (more convenient if connected directly to the ring than to the bed), flow of shielding gas flow and feeding of filler metal by feeders of semiautomatic welding machines;
- checking the compatibility of current parameters with a related WPS;
- checking preheating temperature before the

commencement of the welding of each joint.

2. During welding:
- checking temperature before the commencement of the welding of each layer/run (temperature should be restricted within the range of 100°C to 120°C),
- checking the effectiveness of the grinding of the previous layer/run,
- checking the change of wire specified in a related WPS for filling welding,
- periodic checking of the condition of ring fixings to the bed and the ring shape,
- consistent checking of current parameters,
- if the recording of all parameters is necessary, the recording (for each layer/run) of pre-weld and post-weld temperature and of parameters necessary for calculating heat input (welding current, arc voltage, arc burning time and length of a given weld section),
- checking the correct wrapping of a joint with a heat-insulating cover (to slow down cooling).

3. after welding, ring cooling and removal of fixings along with the technological bed:
- initial NDT: VT (visual tests), MT (magnetic particle tests) and UT (ultrasonic tests) of all the joints,
- geometrical measurements of the ring;
- visual inspection conducted by a classification inspector, who, on the basis of related test and measurement results, performs the initial acceptance of the ring admitting it for mechanical processing;
- after mechanical processing of the ring in order to obtain design dimensions, NDTs are performed again (acceptance tests) along with linear and geometric measurements; a positive result is the basis for the final acceptance by a classification society inspector;
- labelling of the ring (with a classification inspector sign) and issuing a final acceptance certificate.

Summary

The manufacture of large-sized rings of offshore structures, welded of bent shape segments, entails the satisfaction of the following formal and actual requirements (by the manufacturer):
- possessing qualified welding procedures according to a related offshore standard, including all ring parameters and authorised by a classification society;
- employing appropriately qualified implementation and welding coordination personnel;
- being in possession of technical equipment enabling the performance of welding processes satisfying quality and deadline-related requirements;
- extensive technical and organisational preparation;
- if necessary, collaboration with proven subcontractors performing mechanical processing, able to perform machining satisfying quality, deadline and NDT-related requirements (authorised laboratory).

References

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