

NORSOK STANDARD

STRUCTURAL ALUMINIUM FABRICATION

M-102
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Please note that whilst every effort has been made to ensure the accuracy of the NORSOK standards neither OLF nor TBL or any of their members will assume liability for any use thereof.

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FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry initiative to add value, reduce cost and lead time and remove unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and are jointly issued by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Engineering Industries). NORSOK standards are administered by NTS (Norwegian Technology Standards Institution).

The purpose of this industry standard is to replace the individual oil company specifications for use in existing and future petroleum industry developments, subject to the individual company's review and application.

The NORSOK standards make extensive references to international standards. Where relevant, the contents of this standard will be used to provide input to the international standardization process. Subject to implementation into international standards, this NORSOK standard will be withdrawn.

Annex A and B are informative.

1 SCOPE

This NORSOK standard covers the requirements for fabrication and inspection of aluminium structures used in offshore installations.

2 NORMATIVE REFERENCES

The following standards include provisions which, through reference in this text, constitute provisions of this NORSOK standard. Latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used provided it can be shown that they meet or exceed the requirements of the standards referenced below.

ASME, Section V	Non-destructive testing.
BS 8118	Part 2, Structural use of aluminium.
EN 287-2	Approval testing of welders - Fusion welding.
EN 288-4	Specification and qualification of welding procedures for metallic materials.
EN 444	NDT - General principles for radiographic examination of metallic materials by X-rays and gamma rays.
EN 462	NDT - Image quality of radiographs.
EN 473	Qualification and certification of NDT personnel - General principles.
EN 719	Welding coordination - Tasks and responsibilities.
EN 729	Quality requirements for welding - Fusion welding of metallic materials.
prEN 970	Welding - Visual examination of fusion welded joints.
prEN 1011	Recommendation for arc welding of specific requirements for aluminium and its alloy.
prEN 1289	Penetrant testing of welds - acceptance level and criteria.
prEN 1418	Welding personnel - Approval testing for fully mechanised and automatic welding.
prEN 1597-1	Welding consumables - testing for classification.
EN 10204	Metallic products - Types of inspection documents.
ISO 10042	Arc welded joints in aluminium and its weldable alloy (EN 30042)
IIW	Radiographic Atlas
NS 477	Welding. Rules for approval of welding inspectors.
NORSOK M-001	Material selection.
NORSOK M-121	Aluminium structural material.
NORSOK N-001	Structural design

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

Can	Can-requirements are conditional and indicates a possibility open to the user of the standard.
May	May indicates a course of action that is permissible within the limits of the standard (a permission).
Normative references	Shall mean normative in the application of Norsok standards.
Shall	Shall is an absolute requirement which shall be followed strictly in order to conform with the standard.
Should	Should is a recommendation. Alternative solutions having the same functionality and quality are acceptable.

3.2 Abbreviations

BS	British Standard
DAC	Distance Amplitude Curve
EN	Euronorm
FSH	Full Screen Height
IIW	International Institute of Welding
NDT	Non Destructive Testing
PT	Penetrant Testing
RT	Radiographic Testing
SMYS	Specified Minimum Yield Strength
UT	Ultrasonic Testing
WPAR	Welding Procedure Approval Record
WPS	Welding Procedure Specification

4 QUALIFICATION OF WELDING PROCEDURES AND WELDERS

4.1 Welding procedure specification (WPS)

WPS shall be established in accordance with EN 288 part 2.

Information to be stated in WPS in addition to requirement in EN 288-2 as follows:

- Base material standard, alloy and temper
- Max. time limit between cleaning and welding

4.2 Qualification of welding procedures

Welding procedures used for aluminium structures, shall be qualified in accordance with EN 288 part 4 and the additional requirements in this standard. For welds specified in Inspection Category D qualified welding procedures are not required.

The qualification is valid for the workshop performing the welding tests, and other workshops under the same technical and quality management. It may also be transferred to and used by a subcontractor, provided the principles of EN 729 are implemented and documented.

4.3 Welding procedure approval record (WPAR) - Range of approval

The WPAR is valid within the limitations specified in EN 288 part 4, with addition of the following essential variables which require requalification:

- a) a change in heat input of more than + 15% and - 20%. If an approval testing have been performed at both a high and a low heat input level (with all specified mechanical testing), then all intermediate heat inputs are also qualified
- b) a change from extruded aluminium to wrought (rolled, forged) aluminium shall require a new qualification test
- c) an alloy within Group 23 qualifies for other alloys within group 23 with lower SMYS, but not higher
- d) any change in arc characteristics
- e) a change from single pass to multi pass
- f) a change in groove angle beyond $-5^{\circ}/+20^{\circ}$

A qualification of fillet welds carried out on plate thickness equal to or greater than 20 mm, applies for all plate and throat thicknesses.

4.4 Examination of the test weld

Testing shall be performed in accordance with EN 288 - 4.

Bend testing shall be carried out in accordance with EN 288 - 4 using controlled bend test method (wrap around). Bending angle shall be 180° using a mandrel with diameter according to table 3 in EN 288 - 4 (minimum diameter of the mandrel shall be 60 mm for material group 21 and 22a and 70 mm for material group 22b and 23).

The micro examination shall be in accordance with EN 288 - 4. The specimen shall be examined at minimum 20x magnification and shall be free from microcracks.

4.5 Welder and welding operators qualifications

The welders, welding operators and tack welders shall be qualified in accordance with EN 287, prEN 1418 or equivalent. For tack welders, an internal test may be used.

5 FABRICATION AND WELDING REQUIREMENTS

5.1 General

All welding work shall be according to recommendations given in EN 1011, Part 4. The fabricator shall have a quality system, which fulfil the relevant part of EN 729 and the applicable level of EN 719.

The fabricator shall develop a weld numbering system for identification on shop drawings.

Temporary cut-outs shall not be located in restricted areas as shown on design drawings. Temporary cut outs shall have a corner radius not less than 100 mm. Temporary cut-outs shall be closed by refitting the same or an equivalent plate and employing the same welding, inspection and documentation procedures and requirements that govern the structural part in question.

Structural members distorted by welding shall be straightened according to detailed work instruction.

Buttering shall be carried out in accordance with design drawings and a relevant WPS.

5.2 Preparation for welding

All areas to be included in a weld shall be cleaned by mechanical means to remove surface oxide followed by solvent cleaning. The time interval between cleaning and welding shall be as short as possible and shall not exceed 4 hours.

5.3 Welding consumables

For selection of welding consumable reference is made to NORSOK M-121 table 5.1. The manufacturers shall ensure that welding consumables applied for joints meet the requirements for mechanical properties as specified for the welding procedure qualification. This may be achieved through Batch testing including chemical analysis and mechanical properties, see Annex B.

5.4 Preheat and interpass temperature

Preheating above 50°C should be avoided.

If not otherwise stated in the WPS, and qualified by the WPAR, the maximum interpass temperature shall not exceed 100°C measured at the edge of the weld groove.

5.5 Production welding

Welding shall be carried out in accordance with the WPS and applicable drawings.

Butt welds welded without backing shall, whenever possible, be welded from both sides.

Temporary attachments as lifting lugs, lugs for scaffolding and assembly, supports for cables, equipment, ladders or other fabrication and erection aids should be removed. If indicated on design drawings that removal (full or partial) is not required, the temporary attachments may be left as is, or removed only partially.

All welding of attachments shall comply with the requirements for the structure to which they are attached. Temporary attachments shall be cut minimum 3 mm from the base metal and ground. The ground area shall be visually examined.

5.6 Grinding and preparation for coatings

When grinding is specified on design drawings or is instructed as a corrective action, the grinding shall be performed according to a detailed procedure. Grinding tools, direction, surface roughness and final profile shall be specified. Reference samples for typical joints and sections may be prepared and used for acceptance of treated welds. Typical examples of requirements for grinding of joints are given in Annex A.

Edges of plates and sections which are intended to be coated shall be rounded to approximately 2 mm radius, unless stated otherwise on design drawings.

6 PRODUCTION TESTS

Production testing shall be carried out in accordance with an established plan. The tests shall represent main load carrying welds.

Test coupons shall be welded in a manner which realistically simulates the actual production welding, normally as extension of the production weld, and meet the requirements for welding procedure approval tests.

If a production test fails, the reason for the failure shall be determined and remedial action implemented.

7 FABRICATION TOLERANCES

Fabrication tolerances shall be in accordance with drawings. If not defined on drawings BS 8118 Part 2 Appendix A shall apply.

8 NON-DESTRUCTIVE TESTING (NDT)

8.1 General

The inspection class shall be defined by the designer in accordance with NORSOK N-001, and shall be specified on the design drawings.

Prior to fabrication start-up, contractor shall implement a system for recording of weld defect rates. If this system shall be used as basis for a reduction of NDT extent according to table 8.1, the system must ensure that a correct rate identification is prepared for each weld method, each NDT method and each production location.

The defect rate is defined as:

$$\frac{(\text{Defect length} \times 100\%)}{(\text{Length of tested parts of welds})^1}$$

Note 1: "Tested part of welds" means the part that is tested with the same NDT method.

NDT after repair shall not be included when calculating the defect rate.

8.2 Qualification of inspectors and NDT-operators

The NDT operators shall be qualified according to EN 473/Nordtest level 2 or equivalent. Operators simply producing radiographs and not performing evaluation, do not require level 2, but shall have sufficient training and knowledge.

Personnel qualified according to EN 473/Nordtest Level 3 or equivalent shall be responsible for all NDT activities.

Personnel responsible for visual inspection of welds shall be qualified in accordance with NS 477 or an equivalent scheme.

8.3 Extent of visual examination and NDT

The required minimum extent of examination is given in table 8.1. Design drawings may show areas of welds where testing is mandatory.

Table 8.1 Minimum extent (in %) of non-destructive examination for structural welds.

Inspection category	Type of connection	Visual examination	Extent of testing		
			RT	UT	PT
A	Buttw.	100	10	100	100
	T-conn.	100	-	100	100
	Fillet/partial	100	-	-	100
B	Buttw.	100	Spot	100 ¹⁾	100 ¹⁾
	T-conn.	100	-	100 ¹⁾	100 ¹⁾
	Fillet/partial	100	-	-	100 ¹⁾
C	Buttw.	100	-	20 ^{1,2)}	20 ^{1,2)}
	T-conn.	100	-	20 ^{1,2)}	20 ^{1,2)}
	Fillet/partial	100	-	-	20 ^{1,2)}
D	All conn.	100	-	-	spot

Legend -
RT = Radiographic testing
UT = Ultrasonic testing
PT = Penetrant testing
Spot means approximately ca. 5%.

Notes:
1. For fabrication of structures under permanent indoor conditions the extent may be reduced to the half of the specified extent, based on the experience and documented records with similar joints, provided the defect rate for UT is $\leq 5,0\%$, RT $\leq 2,0\%$ and for PT $< 0,2\%$ during the last 100 m of weld. The last 100 m shall be continuously updated every week. If the defect rate exceeds the limits given above, the normal extent of NDT shall apply again. A possible reduction in the extent of NDT shall be considered separately for each welding method and each production area.
2. The extent shall be raised to 100% if the defect rate for UT $> 5,0\%$, RT $> 2,0\%$ and for PT $> 0,2\%$ during the last 100 m of weld, see also Note 1.

When partial testing is defined for welds in an area, the testing shall be spread such that the most essential members and nodes are included in the inspection, and such that areas of welds most susceptible to weld defects are covered.

The specified percentage to be tested in table 8.1 refers to the total length of welds in each inspection class.

All WPS's used and welding personnel involved in the fabrication shall be subject to NDT.

During the initial fabrication the extent of UT and PT of inspection category C welds shall be intensified, normally to twice the level given in table 8.1. This extent shall be maintained for a weld and test length sufficient to conclude that the weld repair percentage is at a reasonable level.

The increased initial testing may be accounted for in the overall extent provided the initial testing confirms consistent good workmanship.

The extent of NDT shall be increased if repeated occurrence of cracks or other significant weld defects are revealed. Corrective actions shall be taken to ensure that all similar defects will be detected.

In addition to what is listed in table 8.1, the following shall apply for inspection category A and B:

- a) Where radiographic testing is required, intersection welds, and those locations where presence of defects is deemed to be most harmful, shall be tested.
- b) Ultrasonic and radiographic testing shall not overlap, except when 100% UT is specified. However, ambiguous imperfections revealed by UT shall in addition be tested by RT.
- c) Ultrasonic testing is normally not applicable for thicknesses less than 10 mm. For such thicknesses, UT may be replaced with RT. In general, RT should be considered if UT is not possible. Radiographic testing is normally not applicable for thicknesses above 40 mm.
- d) PT shall be performed on both external and internal surface as accessible.

8.4 Visual examination

The visual examination shall be carried out in accordance with prEN 970.

8.5 Radiographic testing

Radiographic testing shall be carried out in accordance with EN 444 or ASME V Article 2.

Suspect planar indications discovered by RT shall be type determined, located and sized by UT.

Penetrameters of wire type (according to EN 462-1 or equivalent) shall be utilized. Sensitivity level shall be in accordance with EN 462 part 3, Class A.

8.6 Ultrasonic testing

Ultrasonic testing of butt welds shall be performed in accordance with ASME V Article 5, T-542.7

Note:

ASME V shall be used as a base for ultrasonic testing of aluminium until an NS-EN standard is available. This EN standard being developed in CEN/TC 121/SC5B and has work item 189.

Reference block shall be made in accordance with table 8.2. DAC reference curves shall be produced in accordance with ASME V Article 4, Appendix B-20 and C-20.

The effective test range of a DAC curve shall be determined by the point at which the curve has fallen to 25% FSH, when it will be necessary to raise the curve using reflectors at increased depth. The reference block shall be from a aluminium alloy that is representative for the aluminium alloy to be inspected.

Where ultrasonic testing is to be performed on aluminium extruded products, blocks shall be produced both perpendicular to, and parallel to, the direction of extrusion. The extrusion direction shall be clearly identified.

The actual refracted angle for each probe measured from the reference block or as measured on the actual object being examined, shall be used when plotting indications.

A transfer correction between the reference block and the test surface shall be performed.

Ultrasonic examination procedures shall be sufficiently detailed to ensure 100% of the weld body and heat affected zones are examined for longitudinal defects in accordance with ASME V, Article 5, T-542.7.2.3.

All indications exceeding 20% DAC shall be investigated to the extent that they can be evaluated in terms of the acceptance criteria.

All indications exceeding 50% DAC and having any dimension exceeding 5 mm shall be recorded, unless more stringent requirements are given in table 8.3.

All indications exceeding the acceptance criteria shall be reported. The examination report shall include the position, the echo height, length, depth and type of indication.

Table 8.2 Calibration reference block requirements

Thickness of material to be examined (mm)	Thickness of block	Diameter of hole	Distance of hole from one surface
$10 < t \leq 50$	40 or t	3 mm +/-0.2 mm	t/2 and t/4. Additional holes are allowed and recommended
$50 < t \leq 100$	75 or t		
$100 < t \leq 150$	125 or t	6 mm +/-0.2 mm	
$150 < t \leq 200$	175 or t		
$200 < t \leq 250$	225 or t		
$t > 250$	275 or t		

8.7 Penetrant testing

Penetrant testing shall be carried out in accordance with ASME V, Article 6.

8.8 Acceptance criteria

8.8.1 General

All welds shall show evidence of good workmanship and be verified by relevant type of inspection to comply with the requirements given in table 8.3, 8.4 and 8.5 below.

Table 8.3 Acceptance criteria for visual inspection of welds

Type of defect	Inspection category A and B	Inspection category C and D
<i>Cracks</i>	Not acceptable	Not acceptable
One sided welds: <i>Incomplete root penetration or lack of fusion</i>	Not acceptable	Length < t/2, but max. 10 mm. Defects to be judged as continuous if distance between them is less than t.
<i>Concave root</i>	Until 0,5 mm deep is accepted if smooth transition	
<i>Undercut</i>	Max. depth 0,03t, Max. length 10 mm	Max. depth 0,1t
<i>Surface porosity:</i> a) <i>Single pore:</i> b) <i>Accumulated pore diameters in any 100 mm length to be</i>	$\leq 0,01t$ $\leq 0,05t$	$\leq 0,03t$. $\leq 0,15t$.
<i>Cold lap</i>	Not acceptable	
<i>Butt weld reinforcement and excess root penetration (Fig. 3)</i>	$C_{\max} = 3 \text{ mm}^1$ or 0,1t if higher	$C_{\max} = 6 \text{ mm}$ or 0,2t if higher
<i>Roughness of weld (Fig. 1)</i>	$U_{\max} = 2 \text{ mm}^1$	$U_{\max} = 4 \text{ mm}$
<i>Misalignment of butt welds (Fig. 2)</i>	$M_{\max} = 3 \text{ mm}^1$	$M_{\max} = 6 \text{ mm}$
<i>Reinforcement of fillet welds (Fig. 4)</i>	$C_{\max} = 3 \text{ mm}^1$	$C_{\max} = 6 \text{ mm}$
<i>Symmetry of fillet welds (Fig. 5)</i>	For specified "a" $\leq 6 \text{ mm}$: Max. difference b - h = 3 mm For specified "a" = 7 - 12 mm : Max. difference b - h = 5 mm For specified "a" $\geq 13 \text{ mm}$: Max. difference b - h = 8 mm	
<i>The table continues on the next page</i>		

Notes:

- 1) Localised reinforcements exceeding the above requirements are acceptable
- 2) Temporary attachments shall be flame cut min. 3 mm from the base metal and ground smooth. The ground area shall be visually inspected and PT shall be performed in accordance with the inspection category in question
- 3) When required (ref. 5.6), grinding of the surface shall be specified. Typical examples of grinding requirements are given in Annex A

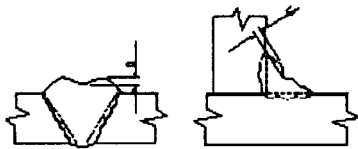


Figure 1 Roughness of weld

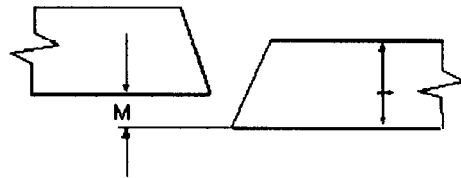


Figure 2 Misalignment of butt weld

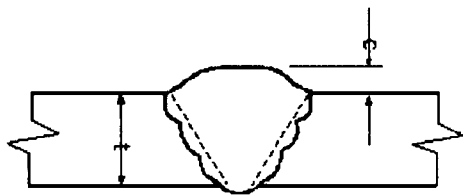


Figure 3 Reinforcement of butt weld

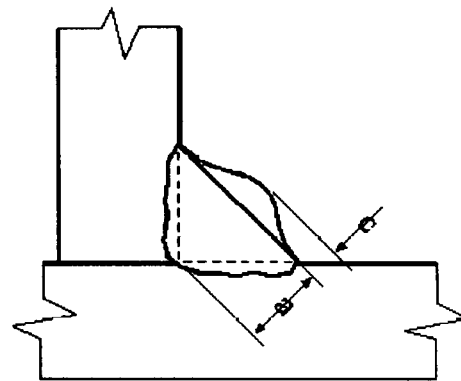


Figure 4a Reinforcement of fillet weld

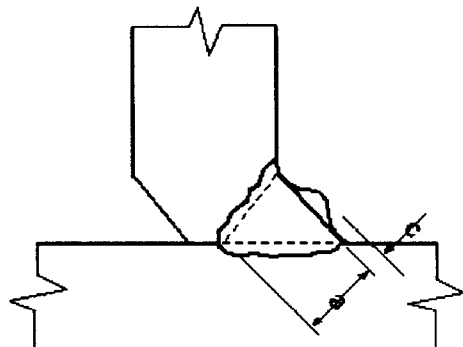


Figure 4b Reinforcement of partial pen weld

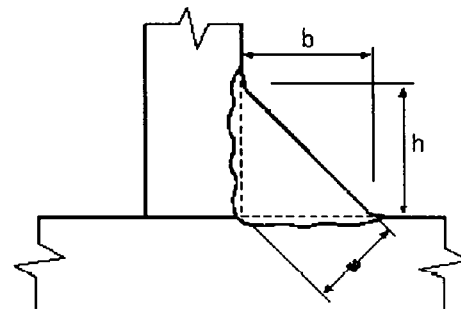


Figure 5 Symmetri of fillet weld

Table 8.4 Acceptance criteria for radiographic inspection of welds

Type of defect	Inspection category A and B	Inspection category C
Cracks	Not acceptable	
Incomplete root penetration (two sided welds) or lack of fusion	Not acceptable	
Porosity a) Single pore: b) Accumulated pore diameters to be better than	< 1,0 mm IIW Mark 4	< t/4 or max. 3 mm IIW Mark 3
Oxides or other inclusions	Not acceptable	Width :< t/4 or max. 3 mm Length :max. 2t or 50 mm

Table 8.5 Acceptance criteria for ultrasonic inspection of welds

Type of defect	Inspection category A and B	Inspection category C
When echo hights exceed the reference curve.		
Cracks	Not acceptable regardless of echo hight	
Lack of fusion and incomplete penetration	Not acceptable	Length max. 2t per 100 mm
Porosity	Repair is required if porosity may mask other defects.	
Oxides or other inclusions	Not acceptable	Length max. 2t or 50 mm

8.8.2 Penetrant testing

Linear indications (i.e. indications with a length/width ratio above 3 and length above 1.5 mm) are not acceptable. Any linear indications shall be ground and re-examined. Rounded indications shall be evaluated in accordance with the requirements of table 8.3.

8.8.3 All methods

All defects shall be repaired according to clause 9.

Defects may be accepted by the relevant parties when repair work is considered detrimental to the total integrity of the weld. Such acceptance shall be the designers responsibility and/or be based on a fitness for purpose evaluation.

9 REPAIR

9.1 Correction of welds containing defects

All repairs shall be carried out in accordance with established procedures.

Welds containing cracks shall not be repaired, until the reason for the cracking has been determined. If necessary, the defective part of the weld shall be cut out for further examination. Crater cracks may be repaired by grinding followed by NDT and subsequent repair welding according to an accepted repair welding procedure.

Other defects shall be corrected by grinding, repair welding or re-welding.

When weld defects are removed by grinding only, the final weld surface and the transition to the base material shall be smooth. Removal of defects shall be verified by local visual inspection, aided by applicable NDT methods. If applicable, the remaining thickness in the ground area shall be measured. Repair welding is required if the remaining thickness is less than that specified.

9.2 Repair by welding

Before repair welding, the defect shall be completely removed. The excavated groove shall be minimum 50 mm long, measured at defect depth even if the defect itself is smaller. Defects spaced less than 100 mm shall be repaired as one continuous defect.

The excavated area shall have smooth transitions to the metal surface and allow good access for both NDT after excavation and subsequent repair welding. After excavation, complete removal of the defect shall be confirmed by PT.

After repair welding the complete weld (i.e. the repaired area plus at least 100 mm on each side) shall be subjected at least to the same NDT as specified for the original weld.

Repair welding may only be carried out twice in the same area.

9.3 Repair welding procedure

Repair and re-repair welding shall be performed in accordance with a qualified WPS.

For repairs using a different process, and/or consumable, a separate WPS shall be developed and/or be qualified if required by 4.2.

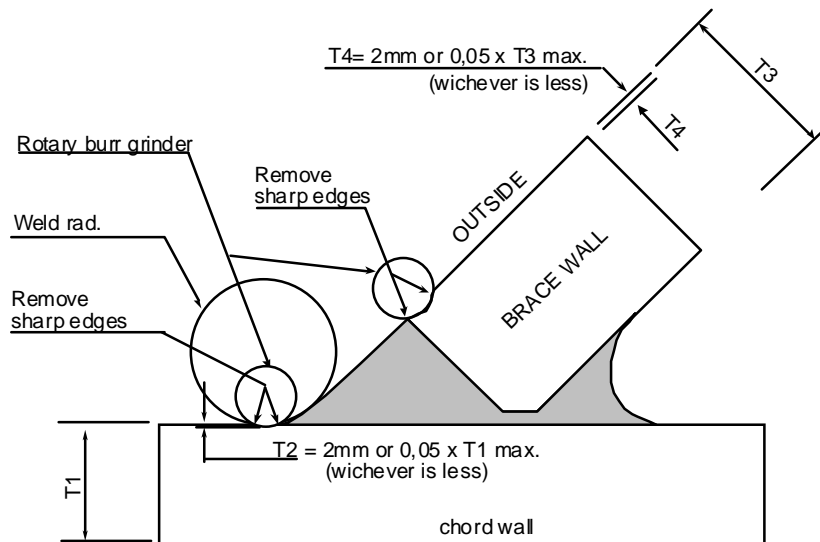
9.4 Correction of distortion

Improperly fitted parts should be cut apart and re-welded in accordance with the applicable qualified WPS.

Parts distorted by welding, beyond the tolerances, should be straightened in accordance with the requirement in clause 4.

ANNEX A TYPICAL PERFORMANCE FOR GRINDING OF WELDS (INFORMATIVE)

TYPICAL GRINDING DETAILS FOR HIGH FATIGUE UTILISATION



TYP. TUBULAR JOINT GRINDING DETAIL

Notes to figure:

1. For removal of undercuts the toe of the weld should be blended in a smooth transition and extended below the plate surface in order to remove the toe defects.
2. Grinding should extend below plate surface to a minimum of 0.5 mm below the bottom of any visible undercut and ensuring that no exposed defects remain, using a rotary burr grinder. Grinding marks should run at right angles to weld axis and under no circumstances parallel to it.
3. Minimum radii of weld profiles after blending should not be less than 10 mm.
4. Upon completion of blending of toe the whole of the ground surface should be inspected with 100% visual examination and 100% PT.
5. Ground surface shall be free of any cracks or cracklike indications, and there shall be no evidence of undercut or overlap.

ANNEX B WELDING CONSUMABLE DOCUMENTED BY BATCH TESTING (INFORMATIVE)

B.1 Scope

The purpose of the batch testing is to verify that the consumables remains nominally equivalent to that used for welding procedure qualification, with respect to chemistry, mechanical properties and porosity.

For this specification a batch (or lot) is defined as the volume of product identified by the supplier under one unique batch/lot number, manufactured in one continuous run from batch controlled raw materials.

Each individual product (brand name and dimensions) shall be tested once per batch.

Chemical Analysis

For solid wires the analysis shall represent the product itself.

The analysis shall include:

- All elements specified in the relevant classification standard and /or intentionally added.
- The main impurities Fe, Cu, Si, Zn.

B.2 Mechanical Properties

Unless otherwise specified the properties shall represent all weld metal, deposited and tested according to prEN 1597 Part 1.

Properties tested shall include:

- Tensile strength, yield strength and elongation.
- Content of porosity.

B.3 Documentation

Batch tests shall be documented by an inspection certificate 3.1B to EN 10 204, with reference to a recognised product classification standard and containing all specified test results.