Part 2 Materials and welding

Chapter 1 General requirements for materials and fabrication
FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

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In this provision "DNV GL" shall mean DNV GL AS, its direct and indirect owners as well as all its affiliates, subsidiaries, directors, officers, employees, agents and any other acting on behalf of DNV GL.
CHANGES – CURRENT

This is a new document.
The rules enter into force 1 January 2016.
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SECTION 1 GENERAL

1 Introduction

1.1 Scope

1.1.1 This chapter specifies general requirements for materials used for construction of vessels and their equipment related to:
— manufacture and manufacturer
— chemical composition
— heat treatment
— inspection and survey
— identification and certification
— testing and retesting
— testing machines
— test specimens and test methods.

1.1.2 The requirements apply for assignment of class.

1.1.3 Upon agreement, the scope may be extended to other applications.

1.2 Application

1.2.1 The requirements apply to:
— testing laboratories
— manufacturers
— builders
— sub-contractors of manufactured, constructed and where relevant, repaired:
  — materials
  — vessels and components.

1.2.2 Upon agreement, the application may be extended to include others.

1.3 Relation to other Society documents

1.3.1 Ch.2 to Ch.4 gives the specific requirements related to manufacture and fabrication of materials, structures and components. Additional requirements may also be provided in Ch.2 to Ch.4, and other parts of the rules, Pt.3 to Pt.7. In case of conflicting requirements, the specific or additional requirements in Ch.2 to Ch.4 and Pt.3 to Pt.7 are prevailing.

2 References

2.1 External references

2.1.1 The external references given in Sec.4 [1] are referred in this chapter. Unless otherwise agreed, the latest version of the referred standards valid at the date of release for the current rules is applicable.
2.2 Terminology and definitions

2.2.1 General terminology and definitions are given in Pt.1 Ch.1 Sec.1 [1.2].

2.3 Abbreviations and symbols

2.3.1 Abbreviations for Pt.1 Ch.1, Ch.2 and Ch.4 are given in Sec.4 [2].

2.3.2 Common symbols in equations and figures, applicable for Pt.1 Ch.1, Ch.2 and Ch.4 are given in Sec.4 [3].

3 Documentation and certification requirements

3.1 Certification requirements

3.1.1 Organisations and personnel shall be certified as required by Table 1.

Table 1 Certification requirements for organizations and personnel

<table>
<thead>
<tr>
<th>Object</th>
<th>Certificate type</th>
<th>Issued by</th>
<th>Additional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials manufacturers</td>
<td>AoM</td>
<td>Society</td>
<td>Approval of manufacturer for materials delivered with VL and W certificate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>This includes manufacturers of semi-finished products (e.g. ingots, blooms, billets)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>for further processing by rolling, forging, drawing, extruding, etc.</td>
</tr>
<tr>
<td>Welding workshops</td>
<td>WWA</td>
<td>Society</td>
<td>Approval of welding workshop</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DNVGL-CP-0352</td>
</tr>
<tr>
<td>Heat-treatment workshops</td>
<td>AoM</td>
<td>Society</td>
<td>Approval of heat-treatment workshop</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DNVGL-CP-0351</td>
</tr>
<tr>
<td>NDT operators / supervisors</td>
<td>-</td>
<td>Body</td>
<td>NDT operator certificate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>recognized by</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>the Society</td>
<td>Certified according to standards or schemes recognized the Society, e.g. ISO 9712,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ASNT Central Certification Program (ACCP). SNT-TC-1A may be accepted if the NDT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>company’s written practice is reviewed and accepted by the Society</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>See further details in Ch.4 Sec.7 [3]</td>
</tr>
</tbody>
</table>

*) unless otherwise specified the certification standard is the rules

3.1.2 For definition of AoM and WWA, see Sec.2 [2].

3.2 Documentation requirements

3.2.1 Four different documentation requirements are defined in Pt.2 - Materials and welding, these are:
— *Qualification documentation for manufacturer (manufacturer specific):* Documentation to be prepared, made available, submitted when required, and stored by the manufacturer  
— *Qualification documentation for builder (builder specific):* Documentation to be prepared, made available, submitted when required, and stored by the builder  
— *Product specific:* Documentation prepared for a defined material/product subjected to certification in accordance with the Society rules. The documentation shall be submitted to the Society for information or approval as specified  
— *Vessel specific:* Documentation prepared for a defined vessel subjected to Classification by the Society. The documentation shall be submitted for information or approval as specified.

For general definition of documentation types, see Pt.1 Ch.3 Sec.3.

### 3.2.2 Qualification documentation for manufacturers

Manufacturers of materials covered by [1.1] and [1.2] shall submit or make available documentation as required in Table 2. For testing that is carried out at independent laboratories or at builders, the requirements apply to the relevant testing laboratory.

**Table 2 Qualification documentation for manufacturer**

<table>
<thead>
<tr>
<th>Item</th>
<th>Documentation type</th>
<th>Additional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials for vessels and their equipment</td>
<td>Z251 - Test procedure</td>
<td>Including details for testing, retesting and non-destructive testing</td>
</tr>
</tbody>
</table>

### 3.3 Survey, inspection and testing requirements

**3.3.1** General survey, inspection and testing requirements are given in Table 3, and further detailed in Sec.2 [3]. Specific requirements are given in Ch.2 to Ch.4.

**Table 3 Survey and testing requirements**

<table>
<thead>
<tr>
<th>Survey, inspection and testing item</th>
<th>Description</th>
</tr>
</thead>
</table>
| Approval of manufacturer | — The manufacturer shall carry out a test program and submit the results, as described in the relevant approval program.  
— The surveyor shall be given the opportunity to witness and survey all relevant processes and tests |
| Manufacturer plant, manufacturing process, materials and product testing | — The surveyor shall be given the opportunity to survey and check at any time all plants and equipment used in the manufacture and testing.  
— The manufacturer shall assist the surveyor to enable him to verify that approved processes are adhered to and to witness the selection and testing as required by the rules |
| Non-destructive testing | — Where non-destructive tests are specified for the various products, these shall be performed under the manufacturer’s responsibility.  
— All tests shall be carried out by personnel qualified and certified in accordance with recognised standards or schemes, see Table 1. When requested, the surveyor shall be furnished with proof thereof.  
— When requested, the surveyor shall be given the possibility of being present during non-destructive tests |
### Survey, inspection and testing item

<table>
<thead>
<tr>
<th>Survey, inspection and testing item</th>
<th>Description</th>
</tr>
</thead>
</table>
| Dimensions and visual inspection   | — All products shall be checked by the manufacturer for compliance with the specified dimensions. The manufacturer shall inspect them for defects. For this purpose and unless otherwise approved, the products shall be in the prescribed delivery condition and shall have a clean surface, prepared for inspection, which is free from coatings or other protective media which impair the detection of defects.  
— Products that do not meet the required dimensions or show unacceptable defects shall be clearly marked accordingly.  
— The products shall, when called for, be presented to the surveyor in the condition described above |
| Chemical composition               | — The chemical composition of samples taken from each ladle cast shall be determined by the manufacturer in an adequately equipped and competently staffed laboratory and shall comply with the appropriate requirements of Ch.2.  
— When possible, the sample for chemical analysis shall be taken during pouring.  
— The manufacturer’s declared analysis will be accepted subject to occasional checks if required by the surveyor |
| Selection and marking of test material | — Where the Society’s certification is required, all the test material shall be selected and marked by the surveyor before they are removed from the sample, unless otherwise agreed |
| Testing of materials                | — The appropriate tests specified in Ch.2 to Ch.4 shall be carried out at the place of manufacture before materials are dispatched.  
— If the necessary facilities are not available at the manufacturer’s works, the testing shall be carried out at a testing laboratory recognized by the Society.  
— Where the Society’s certification is required, all the testing (except for chemical composition analysis) shall be witnessed by the surveyor, unless otherwise agreed.  
— The surveyor may require further tests when deemed necessary.  
— All tests shall be carried out by competent personnel on machines of accepted type |
| Retesting                           | — Requirements for retesting are described in detail in Sec.2 [3.7] |

### 3.4 Evaluation for acceptance of materials specified by other standards

#### 3.4.1 Where indicated in the Rules, materials specified to international, national or proprietary standards may be considered for acceptance by the Society. In order to be considered for acceptance, the suitability of these materials for the intended purpose shall first be evaluated and qualified by the manufacturer or builder. As a minimum, the following particulars shall be specified for alternative materials:

— relevant standard/specification and grade  
— manufacturing process  
— chemical composition  
— heat treatment/delivery condition  
— sampling for mechanical properties testing, e.g. sampling process, sampling frequency, at what stage of manufacturing process, location of sample within the product, sizes, etc.  
— mechanical properties
— dimensional tolerances
— if relevant, non-destructive testing

Further particulars may be required as relevant for the approval. Requirements for approval of manufacturer and certification of materials shall follow Sec.2 [2] and Sec.2 [4].

**Guidance note:**

In order for other materials to be considered for acceptance, a gap analysis report identifying the differences between the proposed material and the corresponding Society rule requirements should be submitted. Note that for all the Society rule requirements not addressed in the relevant standard, or not already accepted based on the manufacturer’s evaluation and qualification, the requirements of the Society rules apply.

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SECTION 2 MANUFACTURE, SURVEY AND CERTIFICATION

1 General

1.1 Application

1.1.1 This section specifies general requirements for manufacture, survey and certification of materials used for the construction or repair of hulls, equipment, boilers and pressure vessels and machinery of vessels classed or intended for classification by the Society. Upon agreement, the scope may be extended to materials, products and applications not explicitly mentioned above. Appropriate specific requirements are given in Ch.2 to Ch.4.

1.1.2 Materials which shall comply with these requirements are defined in the relevant design and construction parts of the rules.

1.1.3 Materials which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to the requirements of Ch.2 or are otherwise specially approved. Information to be supplied by the purchaser

1.1.4 The purchaser shall supply the manufacturer with all information necessary to ensure that survey and certification can be carried out in accordance with these rules. This applies particularly where optional or additional conditions are specified in the relevant construction rules.

2 Approval of manufacturers

2.1 General

2.1.1 Approval of manufacturers and heat-treatment workshops (AoM), and welding workshops (WWA) are schemes to ensure these are qualified for the manufacture, welding and heat-treatment of specified materials and products intended for class.

The objective of AoM and WWA is to verify the manufacturers’ and service suppliers’ ability to consistently manufacture, weld and heat-treat materials, products and structures to a given specification and according to the Society rule requirements.

2.2 Application

2.2.1 In Pt.2, the term “approval of manufacturer” is covering approval of material manufacturers, heat-treatment workshops and welding workshops. Approved manufacturers are published on DNV GL homepage.

2.2.2 Materials delivered with VL or W certificate shall be manufactured at works which have been approved by the Society.

2.2.3 Typical heat-treatments that require heat-treatment workshop approval are:

— annealing
— solution heat treatment
— normalizing
— quenching
— tempering
— stress relieving (including post-weld heat treatment of boilers and pressure vessels)
— surface hardening

Heat treatment and related facilities at a material or component manufacturer approved by the Society; is covered by the approval of the manufacturer.

For pre-heating before welding, and for post-heating after welding at T < 350°C, heat treatment workshop approval is not required.

Workshop approval is not required for post-weld heat-treatment (PWHT) carried out as part of the production welding at the yard using portable equipment (e.g. electric resistance mats or gas torch). Heat-treatment including PWHT using furnace requires heat-treatment workshop approval.

2.2.4 General requirements for approval of welding workshops are given in Ch.4.

Repair welding of materials, carried out by the approved material manufacturers, ref. [2.2.2] do not require additional welding workshop approval, but shall be covered by the material manufacturer approval. For repair by welding, see further requirements in respective sections of Ch.2.

When repair welding of materials is carried out by others, welding workshop approval is required.

2.3 Approval process

2.3.1 In order to be approved, the manufacturer, welding workshop and heat-treatment workshop is required to demonstrate and submit documentation to the effect that the necessary manufacturing, testing and inspection facilities are available and are supervised by qualified personnel. The manufacturer and workshops shall carry out a test program and submit the results to the Society.

Where production steps or testing is carried out by outside bodies, such tasks shall be entrusted by the approved manufacturer or workshop only to those subcontractors, firms or institutes covered by the approval, unless separately approved or otherwise agreed.

2.3.2 Detailed programs for approval testing are given in the relevant Society class programs.

2.3.3 When a manufacturer has more than one works/plant/site or production line and unless otherwise agreed, the approval is only valid for the works/plant/site or production line which carried out the test program.

2.3.4 For suspension or withdrawal of approval of manufacturer certificates, see Pt.1 Ch.1 Sec.4.

3 Testing and inspection

3.1 Survey during manufacture

3.1.1 The surveyor shall be given the opportunity to survey and check at any time all plants and equipment used in the manufacture and testing.

The manufacturer shall assist the surveyor to enable him to verify that approved processes are adhered to and to witness the selection and testing as required by the rules.

3.1.2 Prior to the testing and inspection, the manufacturer shall provide the surveyor with the technical specifications of the order and any conditions additional to the rule requirements.

3.1.3 Where non-destructive tests are specified for the various products, these shall be performed under the manufacturer’s responsibility. The testing operators shall be certified to a recognized scheme see Sec.1 Table 1, General certification required for NDT operators. The results together with details of the test method shall be documented by the manufacturer. When required, the surveyor shall be given the possibility of being present during non-destructive tests. The requirements for test method and acceptance criteria are given in the relevant sections of Ch.2.
3.1.4 All products shall be verified by the manufacturer for compliance with the specified dimensions and surface finish. They shall also be inspected by him for possible defects. For this purpose, the products shall normally be in the prescribed delivery condition and shall have a clean surface, prepared for inspection, which is free from coatings or other protective media which impair the detection of defects. Products that do not meet the required dimensions or show unacceptable defects shall be clearly marked accordingly and separated from the regular production process for clearance.

The products, when this is called for, shall be presented to the surveyor in the condition described above.

3.1.5 If there is reasonable doubt as to the quality of a product, the surveyor may require additional tests to be performed.

3.1.6 The manufacturer shall ensure that delivered materials/products are within radioactive contamination limits permitted by regulatory bodies/agencies, as applicable for the place of manufacture. Specification of acceptance levels for radiation shall be documented in manufacturer’s QA/QC procedures.

3.2 Chemical composition

3.2.1 The chemical composition of samples taken from each ladle of each cast shall be determined by the manufacturer in an adequately equipped and competently staffed laboratory and shall comply with the appropriate requirements of Ch.2.

3.2.2 The manufacturer's declared analysis will be accepted subject to occasional checks if required by the surveyor.

3.2.3 When required, the carbon equivalent value \((C_{eq})\) shall be calculated using the formula:

\[
C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \text{ (\%)}
\]

3.2.4 When required, the cold cracking susceptibility \((P_{cm})\) shall be calculated using the formula:

\[
P_{cm} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B \text{ (\%)}
\]

3.3 Heat treatment

3.3.1 All materials shall be supplied in a condition complying with the appropriate requirements of Ch.2.

3.3.2 Heat treatment shall be carried out in properly constructed furnaces which are efficiently maintained and have adequate means for control and recording of temperature. The furnace dimensions shall be such as to allow the material to be uniformly heated to the specified temperature.

3.4 Selection of test material

3.4.1 Test material sufficient for the required tests shall be provided, and preferably also for possible retest. The test material shall be representative of the test unit or sample product. It shall be securely attached to the sample product until all the specified heat treatments have been completed. If the test unit is reheat treated and the test material for retest was detached, it shall be reattached to the sample product before
new heat treatment is commenced. When stated otherwise in Ch.2, the requirements of Ch.2 apply. Test materials or test specimens shall not be separately heat-treated.

3.4.2 Materials for testing shall be suitably marked in order to ensure traceability to the represented products. Where the Society's certification is required, all test material shall be selected and marked by the surveyor before being removed from the sample, unless otherwise agreed.

3.5 Definitions relevant to testing

3.5.1 The following definitions apply:

*Test unit:* The quantity of products to be accepted or rejected, on the basis of the tests to be carried out on sample products. The term may be applied, for example, to a specific number of products of the same shape and dimensions originating from one heat, or to a length of rolled material (plate or strip) or to a single product (a large forging or casting).

*Sample product:* A single forging, casting, plate, tube or other wrought product selected from a test unit.

*Sample:* A sufficient quantity of material taken from the sample product for the purpose of producing one or more test specimen.

*Test specimen:* Part of the sample, with specified dimensions, machined or un-machined, brought to a required condition for submission to a given test.

3.6 Testing

3.6.1 The appropriate tests specified in Ch.2 to Ch.4 shall be carried out at the place of manufacture before materials are dispatched. If the necessary facilities are not available at the manufacturer's works, the testing shall be carried out at a recognized testing laboratory. Where the Society's certification is required, all the testing (except for chemical composition analysis) shall be witnessed by the surveyor, unless otherwise agreed.

3.6.2 Any material proving unsatisfactory during subsequent processing or fabrication shall be rejected, notwithstanding any previous certification. The surveyor may require further tests of materials from affected test units.

3.7 Retesting

3.7.1 When the result of any test, other than impact test, fails to meet the requirements, two further tests may be made from the same sample. If both of these additional tests are satisfactory, the test unit may be accepted.

3.7.2 When the results from a set of three impact test specimens fail to meet the requirements, the test unit is rejected, or alternatively, three additional test specimens from the same sample may be tested. The results are added to those previously obtained. The test unit may be accepted if:

- the average of all six specimens complies with the requirements, and
- not more than two individual results are lower than the required average and
- of these, not more than one result is below 70% of the specified average value.

3.7.3 If unsatisfactory results are obtained from retests representative of a test unit, see [3.7.2], the product from which the tests were made shall be rejected. The remaining material in the test unit may be accepted provided that two further products are tested with satisfactory result.

3.7.4 When a test unit is rejected, see [3.7.2] and [3.7.3], the remaining products in the test unit may be resubmitted individually for test, and those which give satisfactory results may be accepted.
3.7.5 At the option of the manufacturer, rejected material may be resubmitted after heat-treatment or reheat-treatment, or may be resubmitted as another grade and may then be accepted provided the required tests are satisfactory.

Where the material is submitted to heat treatment or re-heat treatment, all the tests previously performed shall be repeated and the results shall meet the specified requirements.

3.7.6 If any test fails because of faulty specimen preparation, visible defects or (in the case of tensile test) or because of fracturing outside the range permitted for the appropriate gauge length, the defective test specimen may be disregarded and replaced by an additional test specimen of the same type.

3.7.7 If a large proportion of the products fail the tests, e.g. because of constantly recurring manufacturing defects, the entire delivery may be rejected by the Society.

The manufacturer shall determine any cause of recurring manufacture defect and establish countermeasures to prevent its recurrence. Investigation reports to this effect along with additional information required by the Society shall be made available to the surveyor. The frequency and extent of testing for subsequent products is at the discretion of the Society.

Guidance note:
It is the manufacturer’s responsibility to ensure that effective manufacture and process controls, and where relevant, qualified and/or approved processes are implemented and adhered to in production. The approved manufacturing processes may be revisited, and the manufacturer approval certificate may be reconsidered, see [2.3.4].

3.8 Visual and non-destructive testing

3.8.1 Internal and surface defects: All finished material shall have a workmanlike finish and shall be free from internal and surface defects prejudicial to the use of the material for the intended application. Otherwise the material shall comply with the appropriate specific requirements of the subsequent rule chapters.

3.8.2 Correction of defects: When defects are found, these shall be removed by appropriate methods and rectified in accordance with the applicable requirements of Ch.2.

4 Identification and certification

4.1 Identification of materials

4.1.1 The manufacturer shall adopt a system of identification which enables all finished material to be traced to the original cast, including the documentation of all important production steps. The surveyor shall be given full facilities for tracing the materials when required.

4.1.2 Before acceptance, all materials which have been tested and inspected with satisfactory results shall be clearly marked by the manufacturer in at least one place with the following particulars:

a) the Society’s brand, as furnished by the surveyor
b) manufacturer's name or trade mark
c) material grade
d) identification number, cast number or other marking which will enable the full history of the product to be traced
e) the VL certificate number, where applicable and as furnished by the surveyor
f) if required by the purchaser, his order number or other identification marks.

4.1.3 A number of light materials such as shapes and bars weighing ≤ 25 kg per metre may be securely fastened together in bundles. For this case, the manufacturer may mark only the top piece of each bundle, or
alternatively attach a durable label securely to each bundle. The content of the required marking is given in [4.1.2].

4.1.4 The marking is normally made by hard stamping; however, other agreed methods may be accepted.

4.1.5 All marks shall be so applied that their legibility cannot be impaired by the transportation or storage of the products. Where the further processing of the products entails the removal of existing marks, the manufacturer concerned shall apply these to a different spot and shall arrange for the transfer of the Society stamp, unless another solution is adopted.

4.1.6 In the event of any material bearing the Society's brand failing to comply with the test requirements, the brand shall be unmistakably defaced by the manufacturer.

4.2 Certification of materials

4.2.1 Certification of materials will be based on compliance with all specified tests and inspection, as documented in a material certificate or inspection document. The manufacturer shall provide the type of inspection certificate required in the relevant construction rules. Unless otherwise specially approved, certification shall take place at the manufacturer's works and the surveyor shall attend and witness testing and inspection in accordance with the appropriate requirements of Ch.2.

For definition and basic requirements for the certificate types, see Pt.1 Ch.1 Sec.4.

4.2.2 VL certificate for materials; material certificate (MC) issued or validated by the Society: The manufacturer shall be approved by the Society, see [2]. Typical types VL certificates are:
— certificate issued by the Society where the manufacturers documentation is added to the certificate
— certificate issued by the Society
— certificate issued by the manufacturer, e.g. 3.2 according to ISO 10474, and endorsed by the Society.

**Guidance note:**
A VL certificate would normally correspond to an inspection certificate type 3.2 according to ISO 10474, but not vice versa.

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4.2.3 W (works) certificate for materials, material certificate (MC) issued by the manufacturer: The manufacturer shall be approved by the Society, see [2].

**Guidance note:**
A W (works) certificate corresponds to an ISO 10474 type 3.1 inspection certificate. Provided the material complies with the Society's rules and the manufacturer is approved by the Society, a 3.1 inspection certificate corresponds to a W certificate.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.2.4 Material test report (TR or MTR), is a report issued by the manufacturer based on non-specific tests and as further defined in Pt.1 Ch.1 Sec.4.

**Guidance note:**
Type 2.2 inspection certificate in accordance with ISO 10474 will normally be accepted as TR.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

4.2.5 As an alternative to [4.2.1], certification may be based on a manufacturing survey arrangement (MSA), subject to approval by the Society. See also Pt.1 Ch.1 Sec.4.

4.2.6 The inspection certificate shall include the following particulars:
— purchaser's name and order number and if known the vessel identification for which the material is intended
— manufacturer’s name
— description of the product, dimensions, weight etc.
— identification of specification or grade of material
— identification of the cast and product
— ladle analysis for specified elements
— results of all specified inspections (including NDT) and mechanical tests
— condition of supply and where appropriate, details of heat treatment.

Except for rolled steel and unless otherwise agreed, separate inspection certificates shall be issued for each grade of material and each product form.

4.2.7 A product intended for W or VL certification may be made from semi-finished products not produced at the works where it will be finished by final rolling, forging or heat treatment. For this case, the semi-finished product shall be delivered with at least W certificate stating process of manufacture and chemical composition, and with traceable identification. The works at which the material was produced shall be approved. Typical semi-finished products are indicated in Figure 1.

Note:
Where stricter certification requirements for semi-finished products are agreed or are given in the subsequent parts of the rules, the stricter requirements apply.

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4.2.8 Regarding electronic certificates reference is made to Pt.1 Ch.1 Sec.4.

![Figure 1 Overview of typical semi-finished products](image-url)
SECTION 3 TESTING PROCEDURES

1 General

1.1 Scope

1.1.1 This section specifies the requirements for testing machines, test specimens and testing procedures when testing ferrous and nonferrous metals.

1.1.2 Alternative test specimens, such as those complying with recognized national and international standards may be accepted subject to approval by the Society and on condition that the test specimens will give comparable results. The same applies to the given testing procedures.

1.2 Documentation requirements

1.2.1 Qualification documentation for manufacturer

Manufacturers of materials as defined in Sec.1 [1] shall submit or make available documentation as required in Table 1. For testing that is carried out at independent laboratories or at builders, the requirements apply to the relevant testing laboratory.

Table 1 Qualification documentation for manufacturer

<table>
<thead>
<tr>
<th>Item</th>
<th>Documentation type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing equipment and facilities</td>
<td>Z260 - Report</td>
<td>For calibration, shall be available at the manufacturer</td>
</tr>
<tr>
<td>Test specimen dimensions and tolerances</td>
<td>Z100 - Specification</td>
<td>The Society's rules, and ISO 6892 or another agreed recognised standard shall be available at the manufacturer</td>
</tr>
<tr>
<td>Test methods not described in this section</td>
<td>Z251 - Test procedure</td>
<td>Testing not described in this section may be required for certain products. In such cases the testing standard or procedure shall be accepted by the Society</td>
</tr>
<tr>
<td>Fracture mechanics test</td>
<td>Z261 - Test report</td>
<td>Containing information as given in ISO 12135 (paragraph 8 Test report) and in ISO 15653 (paragraph 13 Test report)</td>
</tr>
</tbody>
</table>

1.3 Testing machines type, maintenance and calibration

1.3.1 All tests shall be carried out by competent personnel on machines of accepted type. The machines shall be maintained in satisfactory and accurate condition and shall be recalibrated at approximately annual intervals by a testing authority acknowledged by the Society. A record of such calibrations shall be kept available in the test laboratory.

1.3.2 Tensile testing machine load cells shall be calibrated ±1% in accordance with ISO 7500-1 or another recognised standard.

1.3.3 Impact testing shall be carried out on Charpy V-notch machines calibrated to ISO 148-2, ASTM E23 or equivalent dependent on the testing machine type.
1.3.4 Stationary hardness testing equipment shall be calibrated at least yearly on calibrated test blocks. Portable hardness testers shall be calibrated on calibrated test blocks before and after use each day, or at 4 hours intervals, whichever is smaller. In case the manufacturer’s specification indicates shorter intervals, the manufacturer’s specification shall be followed. In case the calibration after use indicates values outside the calibration tolerances, the measurements performed after the previous calibration have to be repeated after a new calibration of the hardness tester. It shall be verified that the acceptable tolerances for the equipment parameters and the indicating accuracy are complied with in accordance with the appropriate standards.

**Guidance note:**
Examples of standards for calibration are ISO 6506-2 and ISO 6507-2.

---e-n-d-o-f-g-u-i-d-a-n-c-e-n-o-t-e---

2 Preparation of test specimens

2.1 General requirements

2.1.1 The preparation shall be done in such a manner that test specimens are not subjected to any significant cold straining or heating.

2.1.2 If samples are cut from material by flame cutting or shearing, a reasonable margin is required to enable sufficient material to be removed from the cut edges during final machining.

**Guidance note:**
A margin of 10 mm may normally be considered sufficient. Smaller margins may be considered for acceptance subject to approval based on qualification by adequate testing. Qualification testing should at least comprise metallographic test, hardness test profile and comparative mechanical tests.

---e-n-d-o-f-g-u-i-d-a-n-c-e-n-o-t-e---

2.1.3 Where possible, test specimens from rolled materials shall retain their rolled surface on both sides. The surface quality of the specimens shall be as prescribed in the appropriate standards, i.e. notches, grooves and burrs which occur during the preparation of test specimens and which may affect the test results are to be removed.

The dimensional and geometrical tolerances of the specimens shall be as prescribed in the appropriate rules and standards.

2.1.4 If possible, the test specimens shall be taken in such a way that straightening is unnecessary. If test sections have to be straightened, e.g. in the case of transverse specimens from pipes, the straightening operation shall be performed in the cold state and shall not significantly affect the mechanical properties of the material. Tensile specimens taken from the pipe wall in the longitudinal direction shall not be pressed flat between the gauge marks.

2.1.5 Tolerances on tensile specimen dimensions shall be in accordance with ISO 6892 or another agreed recognised standard.

3 Test methods

3.1 Tensile testing at ambient temperature

3.1.1 Yield and Proof stress: Upper yield strength \( (R_{eH}) \) is the highest value of stress measured at the commencement of plastic deformation at yield; often this value is represented by a pronounced peak stress.
When no well-defined yield phenomena exist, the yield strength at 0.2% non-proportional elongation ($R_{p0.2}$) shall be determined unless otherwise stated in the applicable specification. If required by the relevant rules, the yield strength at 1% total elongation ($R_{p1.0}$) shall be determined for austenitic and austenitic-ferritic steels (=duplex) according to the applicable specification.

3.1.2 Tensile strength ($R_m$) is the highest value of stress measured before fracture.

3.1.3 Stress and strain rates for tensile tests: For materials with a modulus of elasticity $\geq 150$ GPa (typically steels including stainless steels) the test shall be carried out with an elastic stress rate between 6 and 60 MPa per second.

For materials with a modulus of elasticity $< 150$ GPa (typically copper, aluminium, titanium, and their relevant alloys) the test shall be carried out with an elastic stress rate between 2 and 20 MPa per second.

After reaching the yield strength ($R_e, R_p, R_t$), the machine speed ($v_c$) for determination of the tensile strength ($R_m$), shall not exceed that corresponding to a strain rate ($e'$) of $0.008 \text{s}^{-1}$. That is:

$$e' = \frac{v_c}{L_c} \leq 0.008 \text{s}^{-1}$$

corresponding to crosshead separation rate $v_c$ [mm/s] of:

$$v_c \leq (L_c \times 0.008)$$

For cast iron the elastic stress rate shall not exceed 10 MPa per second.

3.1.4 Accuracy for yield and tensile strength: The test results shall be stated to an accuracy of 1 MPa [N/mm$^2$].

3.1.5 Elongation: If not otherwise stated, the elongation means elongation determined on a proportional gauge length $5.65\sqrt{S_0}$ or 5 d and has the designation $A_5$ (%).

The elongation may alternatively, after agreement with the Society, be determined on a non-proportional gauge length $L_0$ (i.e. a gauge length having a different ratio to the cross-section). In that case the required minimum elongation $A$ is calculated from the formula given below. However, where stated otherwise in Ch.2, the requirement of Ch.2 applies.

$$A = 2A_5 \left(\frac{\sqrt{S_0}}{L_0}\right)^{0.4}$$

This conversion formula shall only be used for ferritic steels with tensile strength of $\leq 700$ N/mm$^2$ which have not been cold formed, see also ISO 2566.

When proportional specimens other than $L_0 = 5.65\sqrt{S_0}$ or 5 d, or non-proportional test specimens are used, the applied gauge length shall be stated in the certificate, e.g. $A200$ mm = elongation for initial gauge length $L_0 = 200$ mm.

The test results shall be reported to an accuracy of a whole number, e.g. 20.51% is reported as 21%.

Requirements for position of fracture:

A. Fracture within a specified range:

The elongation value is valid if the fracture occurs at least the following distance from the end marks of the gauge length:

- Round test specimen: 1.25 d
- Flat test specimen: $b + a$

B. Fracture outside above specified range:

- if the specified minimum elongation requirement is met, the test may be considered to be valid
- if the specified minimum elongation required is not met, the test is considered invalid and a new test shall be carried out.
3.1.6 Reduction of area (Z): The reduction of area at fracture Z [%] shall be determined only where this is called for in Ch.2.

\[ Z = \left( \frac{S_0 - S_d}{S_0} \right) \cdot 100 \] [%]

The test results shall be stated to an accuracy of 1 %.

3.1.7 Tensile test specimen types and dimensions: For the purpose of determining the different designations related to tensile testing, two different types of test specimens are defined: Round and flat, see Figure 1.

![Figure 1 Tensile test specimens](image)

**Table 2 Dimensions of tensile test specimens**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Proportional flat test specimen, Figure 1</td>
<td>( a ) 25 mm ( b ) ( d ) ( L_0 ) ( L_0 + 2 \sqrt{S_0} ) 25 mm</td>
</tr>
<tr>
<td>B: Non-proportional flat test specimen, Figure 1</td>
<td>( a ) 25 mm ( b ) 200 mm ( L_0 + d/2 ) 25 mm</td>
</tr>
<tr>
<td>C: Proportional round test specimen, Figure 1</td>
<td>- - 14 mm (or 10-20 mm) ( 5 \times d ) ( \geq L_0 + d/2 ) 10 mm(2)</td>
</tr>
<tr>
<td>D: Test specimen for sheet and strips with thickness less than 3 mm, Figure 1</td>
<td>( a ) 12.5 mm ( b ) 50 mm ( L_0 + 2 b ) 25 mm</td>
</tr>
<tr>
<td>E: Full cross-section test specimen with plugged ends, Figure 3</td>
<td>- - ( L_0 + D ) (3) -</td>
</tr>
<tr>
<td>F: Strip specimen (4), Figure 3</td>
<td>Tube wall thickness 12 mm ( 5.65 \sqrt{S_0} ) ( L_0 + 2 b ) -</td>
</tr>
</tbody>
</table>
1) the applied gauge length ($L_0$) may be rounded off to the nearest 5 mm, provided that the difference between the applied gauge length and the calculated gauge length (from [3.1.2]) is less than 10% of calculated gauge length
2) for nodular cast iron and materials with specified elongation less than 10%: $R \geq 1.5 d$
3) $L_c$ is the distance between the grips or the plugs, whichever is the smallest
4) the parallel test length is not to be flattened, but the enlarged ends may be flattened for gripping in the testing machine

3.1.8 Plates, wide flats and sections: For plates, wide flats and sections with thickness 3 mm or more, flat test specimens of full product thickness according to alternatives A and B shall generally be used, see Table 2. When the capacity of the available testing machine is insufficient to allow the use of test specimens of full thickness, the test specimen may be reduced in thickness by machining one of the rolled surfaces. Alternatively, for materials over 40 mm thickness, proportional round test specimen according to alternative C may be used. When round test specimen is used, and unless otherwise specified, it shall be positioned with its axis at one-quarter of the thickness from a rolled surface.

3.1.9 Wrought aluminium alloys: Flat tensile test specimens shall be used for specified thicknesses up to and including 12.5 mm (alternative D, see Table 2), and may be used for thickness exceeding 12.5 mm. The test specimens shall be prepared so that both rolled/pressed/extruded surfaces are preserved. Round specimens may alternatively be used for product thicknesses exceeding 12.5 mm (alternative C, see Table 2). For product thicknesses up to and including 40 mm, the longitudinal axis of the round specimens shall be located at mid-thickness. For product thickness exceeding 40 mm, the longitudinal axis of round specimens shall be located at ¼ of the product thickness measured from one face.

3.1.10 Forgings, bars and castings (excluding grey cast iron): Proportional round test specimen according to alternative C in Table 2 shall be used.

3.1.11 Grey cast iron: The specimen shall have dimensions as stipulated in Figure 2.

Figure 2 Grey cast iron test specimen

3.1.12 Pipes and tubes: Test specimen according to alternative E or F shall be used, see Table 2 and Figure 3. Alternatively, provided sufficient wall thickness, round specimens according to alternative C as prescribed in Table 2 may also be used. Round specimens shall then be taken from the sample in such a way that their axis is located at the mid-point of the wall thickness.
3.1.13 Wires: Wire ropes tensile specimens for single wires and strands are to be performed in accordance with the requirements of Pt.3 Ch.11 Sec.1 [7]. Specimens containing the entire section and the following dimensions are to be tested:

\[
L_0 = 200 \text{ mm} \\
L_C = L_0 + 50 \text{ mm}
\]

3.1.14 Weldments:

Deposit metal tensile test:

Round specimen with the following dimensions shall be used, see Figure 1:

- \( D = 10 \text{ mm} \)
- \( L_0 = 50 \text{ mm} \)
- \( L_C > 60 \text{ mm} \)
- \( R \geq 10 \text{ mm} \)

The tensile test specimens shall be taken so that the longitudinal axis coincides with the intersection between the mid-plane of the weld, and the mid-plane of the plates.

For specially small or large dimensions other specimens may be used after agreement with the classification Society, provided they conform to the geometrical relationship given in Table 2.

Butt weld tensile test, flat specimen:

The weld shall be machined (or ground) flush with the surface of the plate, and the specimen prepared with the following dimensions, see Figure 1:

- \( a = t \)
- \( b = 12 \text{ mm for } t \leq 2 \text{ mm} \)
- \( b = 25 \text{ mm for } t > 2 \text{ mm} \)
- \( L_0 = L_C = \text{width of weld} + 60 \text{ mm} \)
- \( R \geq 25 \text{ mm} \)

As an alternative, test specimens in accordance with ISO 4136 would be accepted.

3.2 Impact testing

3.2.1 Impact testing shall be carried out as Charpy V-notch test according to the specification in question. The average value of three test specimens shall be determined and meet the specified minimum requirement. One individual value may be below the specified value, provided that it is not less than 70% of the specified minimum.
3.2.2 The Charpy V-notch impact toughness is the absorbed energy, expressed in joule (J), the symbol being KV. The test results shall be measured to an accuracy of 1 Joule.

3.2.3 The Charpy impact test machine shall be of a type acceptable to the Society having a gap of 40 mm, a striking velocity between 4.5 and 7 m/sec. and an impact energy of not less than 150 J. The angle between the striking edges of the pendulum shall be 30° with the edge rounded to a radius 2 to 2.5 mm. (Pendulum according to ASTM E 23 will also be accepted.)

The point of impact of the hammer shall be in the centre line of the notch. The test arrangement is shown in Figure 4, with the tolerances given in Table 3.

![Figure 4 Charpy V-notch impact test setup](image)

**Figure 4 Charpy V-notch impact test setup**

**Table 3 Characteristic quantities of the testing machine**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear spacing between supports</td>
<td>$40^{+0.2}_{-0}$ mm</td>
</tr>
<tr>
<td>Radius of curvature of supports</td>
<td>$1^{+0.5}_{-0}$ mm</td>
</tr>
<tr>
<td>Undercut of supports</td>
<td>$11^\circ \pm 1^\circ$</td>
</tr>
<tr>
<td>Angle of peen wedge</td>
<td>$30^\circ \pm 1^\circ$</td>
</tr>
<tr>
<td>Radius of curvature of peen cutter</td>
<td>$2^{+0.5}_{-0}$ mm</td>
</tr>
<tr>
<td>Maximum thickness of pendulum face</td>
<td>18 mm</td>
</tr>
<tr>
<td>Striking velocity of pendulum</td>
<td>5 to 5.5 m/s</td>
</tr>
<tr>
<td>1) Angle between supports and bearing</td>
<td>$90^\circ \pm 0.1^\circ$</td>
</tr>
<tr>
<td>1) Distance between centre of peen and centre of gap between supports</td>
<td>$\pm 0.5$ mm</td>
</tr>
</tbody>
</table>

1) for pendulum impact test machines built before 1983 a value of 4.5 to 7 m/s may be agreed

3.2.4 Samples may be flame-cut but the notch shall not to be closer to a flame-cut edge than 25 mm. The notch shall be made in a single cut by a special milling cutter. The cutter shall be kept sharp so that the
shape of the notch is correct safeguarding that cold working at the base is avoided as far as possible. The cutter shall be systematically checked at intervals not exceeding 100 test specimens.

The notch shall be cut in a face of the impact test specimens which was originally perpendicular to a rolled or forged surface, unless otherwise stated.

3.2.5 Dimensions and tolerances for standard charpy V-notch test specimens shall be as given in Table 4.

**Table 4 Charpy V-notch test specimens**

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Nominal</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>55 mm</td>
<td>± 0.60 mm</td>
</tr>
<tr>
<td>Width - standard test specimen</td>
<td>10 mm</td>
<td>± 0.11 mm</td>
</tr>
<tr>
<td>- sub-size test specimen</td>
<td>7.5 mm</td>
<td>± 0.11 mm</td>
</tr>
<tr>
<td>- sub-size test specimen</td>
<td>5 mm</td>
<td>± 0.06 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>10 mm</td>
<td>± 0.075 mm</td>
</tr>
<tr>
<td>Angle of notch</td>
<td>45°</td>
<td>± 2°</td>
</tr>
<tr>
<td>Depth below notch</td>
<td>8 mm</td>
<td>± 0.075 mm</td>
</tr>
<tr>
<td>Root radius</td>
<td>0.25mm</td>
<td>± 0.025mm</td>
</tr>
<tr>
<td>Distance of notch from ends of test specimen</td>
<td>27.5 mm</td>
<td>± 0.42mm</td>
</tr>
<tr>
<td>Angle between plane of symmetry of notch and longitudinal axis of test specimen</td>
<td>90°</td>
<td>± 2°</td>
</tr>
<tr>
<td>Angle between adjacent longitudinal faces of test piece</td>
<td>90°</td>
<td>± 2°</td>
</tr>
</tbody>
</table>

3.2.6 Standard Charpy V-notch test specimens with width 10 mm shall be used, except when the thickness of the material does not permit this size. In such cases the largest obtainable of the sub-size test specimens with width 7.5 mm or 5 mm shall be used. The required energy values are then reduced to 5/6 and 2/3 of tabulated values, respectively. Impact tests are not required when the material thickness is less than 6 mm, unless otherwise specified.

3.2.7 The temperature shall be controlled sufficiently to ensure uniformity throughout the cross-section of the test specimen at breaking. Unless otherwise agreed, conditioning and specimen transfer shall comply with ISO 148-1 or an equivalent standard.

Test temperature shall be stated in the certificate.

3.2.8 When required, the crystalline proportion of the fracture surface and the lateral expansion at the point of fracture shall be determined. The crystalline proportion of the fracture surface shall then be estimated and
expressed as a percentage of the total area of the fracture. The lateral expansion shall be measured to an accuracy of 0.01 mm on the side opposite the notch, see also ISO 148-1 and ASTM A370.

3.3 Bend testing

3.3.1 Flat bend test specimen as given in Figure 6 shall be used. Edges on tension side to be rounded to a radius of 1 to 2 mm. In addition to the method indicated in Figure 6, the wrap around method is accepted for materials of low strength, e.g. aluminium alloys.

![Figure 6 Bend test specimen](image)
3.3.2 For plates, structural sections and sheets, test specimen with the following dimensions shall be used:

\[
\begin{align*}
a &= \text{as rolled thickness } t \text{ of material} \\
b &= 30 \text{ mm or product width, whichever is smaller}
\end{align*}
\]

If the as rolled thickness \( t \) is greater than 25 mm, it may be reduced to 25 mm by machining on the compression side of the bend test specimen.

3.3.3 Face and root bend of butt welded joints: The test specimens shall be prepared perpendicular to the weld, with dimensions as follows:

\[
\begin{align*}
a &= t \text{ (as rolled thickness of the plate)} \\
b &= 30 \text{ mm}
\end{align*}
\]

The weld shall be machined flush with the surface of the plate.

If the as rolled thickness \( t \) is greater than 25 mm, it may be reduced to 25 mm by machining on the compression side of the test specimen.

When a longitudinal face-bend or root-bend weld test is required, a test specimen according to an appropriate standard will be accepted.

3.3.4 Side bend of butt welded joints: The test specimens shall be prepared perpendicular to the weld, with dimensions as follows:

\[
\begin{align*}
a &= 10 \text{ mm} \\
b &= t \text{ (as-rolled thickness of the plate)}
\end{align*}
\]

If \( t > 40 \text{ mm} \), the side bend test specimen may be subdivided, each part being at least 20 mm wide.

3.3.5 Unless otherwise detailed in the respective rules or standard, the mandrel diameter shall be \( 4 \times a \) (four times specimen thickness) for materials with SMYS < 550 MPa, and \( 5 \times a \) for materials with SMYS ≥ 550 MPa.

For materials with specified elongation < 20% the mandrel diameter calculated in accordance with ISO 15614-1 is accepted as an alternative.

The bending angle shall be 180°.

3.4 Drop-weight testing

3.4.1 For material with thickness \( t \geq 16 \text{ mm} \), drop-weight test specimens for the determination of nil ductility transition temperature shall comply with specifications given in ASTM E208 or equivalent international or national standard, and have one of the following sizes:

- No. 1: 25 by 90 by 360 mm
- No. 2: 19 by 50 by 130 mm
- No. 3: 16 by 50 by 130 mm.

The test specimen dimensions shall be based on the largest obtainable thickness. Where the testing is performed by heats, specimens shall be taken from the thickest product.

The correct specimen thickness shall be achieved by machining the compression side.

The long sides of the test specimens shall be made with a saw cut or, in the case of specimens obtained by thermal cutting, shall be machined with a machining allowance of at least 25 mm.

When drop weight test is required for material thicknesses below 16 mm down to and including 12 mm, a test specimen machined down to 12 mm thickness shall be used. For material thicknesses below 12
mm down to and including 10 mm, the thickness of the test specimen shall be that of the material. Other dimensions and requirements for test specimen with thickness below 16 mm shall be as for test specimen no. 3 above, except that a stop distance of 2.3 mm shall be used.

3.4.2 The test specimens may be cut with their axes either transverse or longitudinal to the final rolling direction of the material, but the orientation shall be the same for all test specimens.

3.4.3 Two test specimens shall be tested at the prescribed test temperature. Both test specimens shall exhibit a non-break performance, i.e. the nil ductility transition temperature shall be below the test temperature.

3.4.4 The drop-weight test shall be carried out and evaluated in accordance with ASTM E208.

  Guidance note:
  Note that one of the criteria for the test to be considered valid is that the striking tip of the weight shall strike within 2.5 mm of a line on the compression side of the specimen, normal to a long edge and directly opposite the notch in the crack-starter weld, see ASTM E208.

3.5 Ductility test for pipes and tubes

3.5.1 Unless otherwise specified in an applicable standard referred in Ch.2 to Ch.4, the following apply.

3.5.2 Pipe flattening test: A section of pipe equal in length to 1.5 times the pipe diameter, but not less than 10 mm and not more than 100 mm, shall be flattened between two plates to the prescribed distance or until fracture occurs, see Figure 7. In the case of welded pipes, the weld shall be located in the 3 or 9 o’clock position relative to the setup given in Figure 7.

After the test, the specimens shall be thoroughly examined for defects with normal visual acuity. The test shall be satisfactory if the specimen, having been flattened to the prescribed distance, is free from cracks and did not fracture.

The dimensions of the pipe section, the distance H between the flattening plates as well as the position of the welding joint are to be stated. Example of applicable standard is ISO 8492.

![Figure 7 Pipe flattening test](image)
### 3.5.3 Drift expanding test

To perform this test, a tapered drift is forced into the specimen until the outside diameter has increased to the prescribed value \( C \) for the product in question, see Figure 8.

The length of the specimen and the taper angle \( \beta \) of the drift shall be as shown in Table 5.

The intrusion rate of the taper shall not exceed 50 mm/s.

After the test, the specimens shall be thoroughly examined for defects with normal visual acuity. Unless otherwise specified in Ch.2, the test results are satisfactory if the prescribed expansion has been effectuated without cracks.

\[
C = \text{Diameter after the prescribed expansion}
\]

The dimensions of the pipe section, the outer diameter \( C \) of the expanded part of the pipe section or the relative expansion [%], as well as the taper angle shall be stated. Example of standard to be applied, see ISO 8493.

#### Figure 8 Drift expanding test

**Table 5 Drift expanding test specimen dimensions**

<table>
<thead>
<tr>
<th>Material</th>
<th>Length of specimen, ( L )</th>
<th>Taper angle, ( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>( \leq 2 , D )</td>
<td>30°</td>
</tr>
<tr>
<td></td>
<td>( \leq 1.5 , D; ) Min. 50 mm</td>
<td>45°, 60° or 120°</td>
</tr>
<tr>
<td>Copper and copper alloys</td>
<td>2 , D</td>
<td>45°</td>
</tr>
<tr>
<td>Aluminium alloys</td>
<td>( \geq 2 , D ) Min. 50 mm</td>
<td>60°</td>
</tr>
</tbody>
</table>

### 3.5.4 Flanging test

To perform this test, a sample of pipe with a length \( L = 1.5 \, D \) shall be worked into a flange in the device shown in Figure 9 until the outer diameter \( C \) of the flange attains the value prescribed for the product. The radius \( r \) shall match that prescribed for the product. The intrusion rate of the tool may not exceed 50 mm/min.

Acceptance criteria: The test results are satisfactory if the flange has no apparent cracks. Minor defects on the edges may be disregarded.
The dimensions of the pipe section, the outer diameter \( C \) of the expanded part of the pipe section or the relative expansion \([\%]\), as well as the edge radius of the forming tool are to be stated.

**Guidance note:**
Example of standard to be applied; ISO 8494.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

\[ C = \text{Diameter after the prescribed expansion} \]

**Figure 9 Flanging test**

3.5.5 *Ring expanding test* To perform this test, sections of pipe measuring 10 to 16 mm in length \( L \) shall expanded to the prescribed diameter \( C \) or until fracture occurs using a drift with a taper of about 1:5. Where necessary, more than one test shall be performed with drifts of increasing diameter. The superimposition of several specimens of the same size and steel grade is permitted, see **Figure 10**.

The intrusion rate of the mandrel shall not exceed 30 mm/s.
Figure 10 Ring expanding test

The dimensions of the pipe sections, the outer diameter C of the expanded part of the pipe section or the relative expansion [%], as well as the ratio of the taper (if not 1:5) shall be stated. Example of standard to be applied; ISO 8495.

After the test, the specimens shall be thoroughly examined for defects with normal visual acuity, and the ductility of the pipes shall be assessed by reference to the expansion achieved and, where applicable, to the appearance of the fracture surface.

Acceptance criteria: The test results are satisfactory if the prescribed expansion has been reached without fracture, and the specimen reveals no unacceptable defects such as scabs, laps, cracks, grooves or laminations.

3.5.6 Ring tensile test

The sections of pipe measuring about 15 mm in length shall have plane and smoothed ends and shall be at right angle to the pipe axis. To perform this test, the pipe sections are stretched in a tensile testing machine until fracture occur using two pins with a diameter equal to at least three times the wall thickness of the pipe, see Figure 11. In the case of welded pipes, the specimen shall be placed in the tensile testing device in such a way that the welded seam lies at 90° to the direction of the tensile load. The rate of the pins may not exceed 5 mm/s.
3.6 Hardness test

3.6.1 Where hardness test is required, the tests shall be performed in accordance with a recognized standard, e.g. for Brinell, Vickers or Rockwell hardness:

— ISO 6506 Brinell Hardness Test
— ISO 6507 Vickers Hardness Test
— ISO 6508 Rockwell Hardness Test

3.6.2 Hardness test is generally not considered to be a substitute for tensile test.

3.7 Determination of grain size

3.7.1 Where the austenitic grain size is specified, it shall be determined according to methods described in recognized standards. At least one sample shall be taken from finished material from each ladle. For rolled products the sample is preferably to be taken from the thickest piece rolled. The grain size numbers refer to the ASTM scale described in ASTM E112.

3.8 Strain age test

3.8.1 The material shall first be strained using either an oversized tensile test specimen, or by the straining method applied in production, e.g. cold bending or cold rolling. Other methods may be accepted case by case.

3.8.2 The straining shall be carried out to a deformation rate corresponding to maximum deformation in production. Formulas for calculation of deformation are given in Ch.4 Sec.6 [5.2]. Unless otherwise agreed, the straining direction for simulated cold forming shall be parallel to the main rolling direction, and the tensile and impact test specimen orientation shall be as specified for the original plate, see Ch.2 Sec.2 [2.8]
3.8.3 The strained material shall then be aged in furnace at a specified temperature for a given time. Unless otherwise specified or agreed, the ageing shall be carried out at 250°C for one hour.

3.8.4 Unless otherwise agreed, the impact test specimens shall be located as close as possible to the surface. For bends, the test specimens shall be as close as possible to the outer radius of the bend (the extrados surface). The notch shall be in the through thickness direction.

3.8.5 The strain-aged material shall be impact tested and satisfy the requirements given for the base material.

3.8.6 Where specified or agreed, the material shall be tensile tested and the elongation shall satisfy an agreed requirement.

3.9 Fracture mechanics testing

3.9.1 When specified, fracture mechanics (FM) testing of materials and weldments shall be performed. The tests shall be carried out according to ISO 12135 (for base material) and ISO 15653 (for welded joints) using 3-point bend specimens (SENB), or another recognized standard as agreed with the Society. Both B x 2B and B x B specimens may be used, although B x 2B specimens are recommended. The test is deemed to be valid provided post-test-data analysis meets all validity criteria of the standard. For further requirements concerning test equipment, fatigue (pre)cracking, test performance, evaluation and validity reference is made to ISO 12135.

The specimen width B shall be the full plate thickness, i.e. when machining the specimens the width B has to be at least \( B_{\text{min}} = 0.9 \ t \) (\( t \) = plate thickness).

The orientation of the specimen shall be perpendicular to the rolling direction, i.e. the notch is oriented parallel to the rolling direction. The notch shall be machined in through thickness direction of the plate. If test temperature is not otherwise specified, it shall be -10°C.

3.9.2 The test may be required for the base material or for a welded connection.

For base metal at least three valid CTOD tests shall be obtained. For welded plates for each required crack tip position at least three valid CTOD tests shall be obtained. The acceptance criteria are given in the relevant sections of Ch.2 and Ch.3.

The test results report shall contain the information as given in ISO 12135 (paragraph 8 Test report) and in ISO 15653 (paragraph 13 Test report), the force (F) - notch opening displacement (V) records and photographs for the fractured surfaces on which the crack lengths are measured.

3.9.3 For welded connections, the test weld shall be made and tested for the actual combination of steel grade, manufacturer, welding process and welding consumable (brand) used.

3.9.4 Requirements for FM testing of welds:

The FM tests shall be carried out on a full penetration butt-weld with K- or single V-bevel preparation (single V-bevel with one edge with a given angle to the surface, the other edge perpendicular to the surface). The notch of the FM test specimen shall be perpendicular to the plate surface. Tests on either of these weld bevel preparations qualify for all types of bevels.

Depending on the requirements, the crack tip shall be positioned either in the weld metal (weld positional, WP), or in the specified microstructure (SM). The specified microstructure is the grain coarsened heat affected zone (GCHAZ) unless otherwise agreed. For SM specimens, the crack tip shall be located at the back of the K or at the perpendicular side of the V. The fusion boundary shall be identified, e.g. by etching with a suitable reagent.

3.9.5 Unless otherwise detailed in the respective Rules, the following applies:

— test weld shall be welded with a heat input representing the maximum heat input used in the fabrication
— test on a plate with thickness t qualifies the thickness range 0.5t to 1.1t.

3.9.6 On each test weld at least three FM test specimens shall be tested.

3.9.7 Metallographic sections to be tested according to ISO 15653 shall be prepared from each GCHAZ specimen. The metallographic section shall include weld metal and base metal. If necessary, in order to determine the exact location of the fatigue pre-crack, sections from both sides of the pre-crack shall be prepared. The faces of the metallographic sections shall not be taken deeper than the deepest point of the fatigue pre-crack and not more than 3 mm from the deepest point of the fatigue pre-crack. Figure 12 shows a cross-section through the weld of an un-fractured specimen.

\[ BM = \text{Base Material} \]
\[ WM = \text{Weld Metal or deposit} \]
\[ d_f = \text{distance from the plane of the fatigue pre-crack to the fusion line (varies along the fatigue pre-crack)} \]
\[ \lambda_i = \text{length (in mm) of each area with acceptable location of the fatigue pre-crack (given as SM (}\lambda) = \text{specified microstructure in ISO 15653)} \]
\[ t = \text{plate thickness} \]

Within the central 75% of the plate thickness the areas where \( d_f \leq 0.5 \text{ mm} \) shall be identified (considered GCHAZ). The length \( \lambda_i \) of each of these areas shall be determined. The location of the fatigue pre-crack shall satisfy the following criteria:

\[ \sum N \lambda_i = \begin{cases} \geq 3 \text{ mm for } t \leq 20 \text{ mm} \\
\geq 0.15 \ t \text{ for } 20 < t \leq 80 \text{ mm} \\
\geq 12 \text{ mm for } t > 80 \text{ mm} 
\end{cases} \]

\[ N = \text{number of areas with } d_f \leq 0.5 \text{ mm} \]

3.9.8 If the location of the fatigue pre-crack of the GCHAZ does not satisfy the specified requirement, the results from the testing are not valid.
ISO 15653 shall be complied with for both GCHAZ (in addition to above requirements) and weld deposit specimens. Unless otherwise specified in the respective rules, three or more valid tests for each of weld deposit and GCHAZ shall be carried out.

3.10 Crack arrest test

3.10.1 When specified, a crack arrest test shall be performed in order to determine the materials ability to arrest a running brittle crack. Appropriate tests are the ESSO test determining a brittle crack arrest toughness value $K_{ca}$, or the double tension wide plate test determining the crack arrest temperature (CAT), or equivalent tests. The use of small scale tests parameters such as the nil ductility test temperature (NDTT) may be considered provided a sound relationship between the obtained test results, e.g. NDTT, and a corresponding $K_{ca}$ or CAT is established. For test method requirements, see relevant AoM program DNVGL-CP-0348.

3.11 Other testing

3.11.1 Testing not described in this section may be required for certain products. In such cases the testing standard or procedure shall be accepted by the Society.
SECTION 4 REFERENCES, ABBREVIATIONS AND SYMBOLS

1 References

A list of references given for Ch.1. Unless otherwise agreed, the latest version of the referred standards valid at the date of release for the current rules is applicable.

Table 1 References

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<tr>
<th>Reference</th>
<th>Title</th>
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<tbody>
<tr>
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<td>ASTM E208</td>
<td>Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels</td>
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<td>ISO 148-1</td>
<td>Metallic materials - Charpy pendulum impact test - Part 1: Test method</td>
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<tr>
<td>ISO 148-2</td>
<td>Metallic materials - Charpy pendulum impact test - Part 2: Verification of testing machines</td>
</tr>
<tr>
<td>ISO 2566</td>
<td>Steel - Conversion of elongation values</td>
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<td>ISO 4136</td>
<td>Destructive tests on welds in metallic materials – Transverse tensile test</td>
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<td>ISO 6506</td>
<td>Metallic materials - Brinell hardness test</td>
</tr>
<tr>
<td>ISO 6506-2</td>
<td>Metallic materials - Brinell hardness test - Part 2: Verification and calibration of testing machines</td>
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<tr>
<td>ISO 6507</td>
<td>Metallic materials - Vickers hardness test</td>
</tr>
<tr>
<td>ISO 6507-2</td>
<td>Metallic materials - Vickers hardness test - Part 2: Verification and calibration of testing machines</td>
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<td>ISO 6508</td>
<td>Metallic materials - Rockwell hardness test</td>
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<td>ISO 6892</td>
<td>Metallic materials - Tensile testing</td>
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<td>ISO 8492</td>
<td>Metallic materials - Tube - Flattening test</td>
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<td>Metallic materials - Tube - Drift-expanding test</td>
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<td>ISO 8495</td>
<td>Metallic materials - Tube - Ring-expanding test</td>
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<td>ISO 8496</td>
<td>Metallic materials - Tube - Ring tensile test</td>
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<td>ISO 7500-1</td>
<td>Metallic materials - Verification of static uniaxial testing machines - Part 1: Tension/compression testing machines - Verification and calibration of the force-measuring system</td>
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<tr>
<td>ISO 10474</td>
<td>Steel and steel products - Inspection documents</td>
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<tr>
<td>ISO 12135</td>
<td>Metallic materials - Unified method of test for the determination of quasistatic fracture toughness</td>
</tr>
<tr>
<td>ISO 15653</td>
<td>Metallic materials - Method of test for the determination of quasistatic fracture toughness of welds</td>
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## 2 Abbreviations

Abbreviations for Ch.1, Ch.2 and Ch.4.

### Table 2 Abbreviations

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<th>Abbreviation</th>
<th>Full text</th>
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<tr>
<td>A.C.</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>ACCP</td>
<td>ASNT Central Certification Program</td>
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<tr>
<td>ALS</td>
<td>Accidental Limit State</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>AoM</td>
<td>Approval of Manufacturer</td>
</tr>
<tr>
<td>AP</td>
<td>Approval</td>
</tr>
<tr>
<td>AR</td>
<td>As-Rolled</td>
</tr>
<tr>
<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing of Materials</td>
</tr>
<tr>
<td>AWS</td>
<td>American Welding Society</td>
</tr>
<tr>
<td>BCA</td>
<td>Brittle Crack Arrest</td>
</tr>
<tr>
<td>BM</td>
<td>Base Material</td>
</tr>
<tr>
<td>CAT</td>
<td>Crack Arrest Temperature</td>
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<tr>
<td>CE</td>
<td>Carbon Equivalent</td>
</tr>
<tr>
<td>Ceq</td>
<td>Carbon Equivalent</td>
</tr>
<tr>
<td>C-Mn</td>
<td>Carbon Manganese</td>
</tr>
<tr>
<td>CTOD</td>
<td>Crack Tip Opening Displacement</td>
</tr>
<tr>
<td>D</td>
<td>Diameter</td>
</tr>
<tr>
<td>DAC</td>
<td>Distance Amplitude Curve</td>
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<tr>
<td>DAT(-X°C)</td>
<td>Lowest Daily Average Temperature, see Pt.6. Class notation indicating the design temperature applied as basis for approval</td>
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<tr>
<td>D.C.</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsches Institut für Normung (German Standards)</td>
</tr>
<tr>
<td>ECA</td>
<td>Engineering Critical Assessment</td>
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<tr>
<td>EN</td>
<td>European Standard</td>
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<td>ESSO test</td>
<td>Large scale fracture arrest test for determination of the brittle crack arrest toughness value Kca</td>
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<tr>
<td>ET</td>
<td>Eddy current Testing</td>
</tr>
<tr>
<td>FCAW</td>
<td>Flux Cored Arc Welding</td>
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<tr>
<td>FI</td>
<td>For Information</td>
</tr>
<tr>
<td>FL</td>
<td>Fusion Line</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
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<td>--------------</td>
<td>------------</td>
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<tr>
<td>FM</td>
<td>Fracture Mechanics</td>
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<td>GCHAZ</td>
<td>Grain Coarsened Heat Affected Zone</td>
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<td>GMAW</td>
<td>Gas Metal Arc Welding</td>
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<tr>
<td>GTAW</td>
<td>Gas Tungsten Arc Welding</td>
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<tr>
<td>HAZ</td>
<td>Heat Affected Zone</td>
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<td>HV</td>
<td>Vickers Hardness</td>
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<tr>
<td>IACS</td>
<td>International Association of Classification Societies</td>
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<tr>
<td>IACS UR</td>
<td>IACS Unified Requirements</td>
</tr>
<tr>
<td>IIW</td>
<td>International Institute of Welding</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>JIS</td>
<td>Japanese Industry Standard</td>
</tr>
<tr>
<td>L</td>
<td>Length</td>
</tr>
<tr>
<td>MAG</td>
<td>Metal Active Gas (welding)</td>
</tr>
<tr>
<td>MC</td>
<td>Material Certificate</td>
</tr>
<tr>
<td>MIG</td>
<td>Metal Inert Gas (welding)</td>
</tr>
<tr>
<td>MPa</td>
<td>Mega Pascal</td>
</tr>
<tr>
<td>MSC</td>
<td>Maritime Safety Committee</td>
</tr>
<tr>
<td>MT</td>
<td>Magnetic particle Testing</td>
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<td>MTR</td>
<td>Material Test Report</td>
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<tr>
<td>N</td>
<td>Normalized</td>
</tr>
<tr>
<td>NACE</td>
<td>National Association of Corrosion Engineers</td>
</tr>
<tr>
<td>NDT</td>
<td>Non-Destructive Testing</td>
</tr>
<tr>
<td>NDTT</td>
<td>Nil-Ductility Test Temperature</td>
</tr>
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<td>NR</td>
<td>Normalising Rolling</td>
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<td>NSA</td>
<td>New Building Survey Arrangement.</td>
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<td>Pcm</td>
<td>Cold cracking susceptibility</td>
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<td>Pt.X Ch.Y Sec.Z</td>
<td>DNV GL Rules Part X Chapter Y Section Z</td>
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<tr>
<td>PWHT</td>
<td>Post-Weld Heat Treatment</td>
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<tr>
<td>pWPS</td>
<td>Preliminary Welding Procedure Specification</td>
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<tr>
<td>QT</td>
<td>Quenched and Tempered</td>
</tr>
<tr>
<td>R</td>
<td>On Request</td>
</tr>
<tr>
<td>RCB</td>
<td>Material grade suffix for steels grades of improved corrosion resistance for upper surface of inner bottom plating and surrounding structures</td>
</tr>
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</table>
### Symbols

Common symbols in equations and figures, applicable for Ch.1, Ch.2 and Ch.4.

#### Table 3 Symbols

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<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Unit</th>
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<tbody>
<tr>
<td>a</td>
<td>1) Thickness of tensile test specimens</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>2) Width of abutting member for qualification of TKY welding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) Length related to qualification of welding of pipe branch connection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) Throat thickness of fillet welds</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Percentage elongation after fracture</td>
<td>%</td>
</tr>
<tr>
<td>A₀</td>
<td>Required non-proportional elongation</td>
<td>%</td>
</tr>
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</table>

RCU: Material grade suffix for steels grades of improved corrosion resistance for lower surface of strength deck and surrounding structures

RCW: Material grade suffix for steels grades of improved corrosion resistance for both strength deck and inner bottom plating

RP: Recommended Practice

RT: Radiographic Testing

SAW: Submerged Arc Welding

SENB: Single-Edge Notch Bend

SMAW: Shielded Metal Arc Welding

SMYS: Specified Minimum Yield strength

SOLAS: International Convention for the Safety of Life At Sea

TIG: Tungsten Inert Gas (welding)

TM: Thermo-Mechanical rolling

TR: Test Report

UT: Ultrasonic Testing

VL: Prefix for DNV GL material grades and for DNV GL Certificates

VT: Visual Testing

W: Works Certificate

WM: Weld Metal or deposit

WPQR: Welding Procedure Qualification Records

WPQT: Welding Procedure Qualification Test

WPS: Welding Procedure Specification

WPT: Weld Production Test

WWA: Welding Workshop Approval
<table>
<thead>
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<th>Symbol</th>
<th>Description</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>A&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Elongation in % for test specimen with proportional gauge length</td>
<td>%</td>
</tr>
<tr>
<td>Ac&lt;sub&gt;1&lt;/sub&gt;</td>
<td>The temperature at which austenite begins to be formed upon heating a steel</td>
<td>°C</td>
</tr>
<tr>
<td>Ac&lt;sub&gt;3&lt;/sub&gt;</td>
<td>The temperature at which the transformation of ferrite to austenite is completed upon heating a steel</td>
<td>°C</td>
</tr>
<tr>
<td>Ar&lt;sub&gt;3&lt;/sub&gt;</td>
<td>The temperature at which austenite begins to convert to ferrite upon cooling a steel</td>
<td>°C</td>
</tr>
<tr>
<td>α</td>
<td>Angle</td>
<td>Deg</td>
</tr>
<tr>
<td>b</td>
<td>Width</td>
<td>mm</td>
</tr>
<tr>
<td>B</td>
<td>Width</td>
<td>mm</td>
</tr>
<tr>
<td>B&lt;sub&gt;min&lt;/sub&gt;</td>
<td>Minimum specimen width</td>
<td>mm</td>
</tr>
<tr>
<td>C</td>
<td>Outer diameter after expansion</td>
<td>mm</td>
</tr>
<tr>
<td>C&lt;sub&gt;eq&lt;/sub&gt;</td>
<td>Carbon equivalent</td>
<td>%</td>
</tr>
<tr>
<td>C&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Maximum carbon content</td>
<td>%</td>
</tr>
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</table>
| d      | 1) Test specimen diameter  
         | 2) Journal diameter (forgings)                                              | mm     |
| d<sub>f</sub> | Distance from the plane of the fatigue pre-crack to the fusion line (varies along the fatigue pre-crack) | mm     |
| d<sub>max</sub> | Maximum diameter                                                           | mm     |
| d<sub>min</sub> | Minimum diameter                                                           | mm     |
| D      | 1) External pipe diameter  
         | 2) Diameter of toothed portion of gears                                    | mm     |
| e      | Plastic deformation degree                                                 | %      |
| e'     | Strain rate                                                                 | s<sup>-1</sup> |
| F      | Force                                                                       | N      |
| K<sub>ca</sub> | Brittle crack arrest toughness value                                      | N/mm<sup>3/2</sup> |
| KV     | Charpy V-notch impact toughness absorbed energy                             | J      |
| KV<sub>L</sub> | Impact tested in longitudinal direction                                    | J      |
| KV<sub>T</sub> | Impact tested in transverse direction                                      | J      |
| l      | 1) Longitudinal direction  
         | 2) Length                                                                   | mm     |
| l<sub>min</sub> | Minimum length                                                             | mm     |
| L      | 1) Length of test sample  
<pre><code>     | 2) Length of toothed portion of gears                                       | mm     |
</code></pre>
<p>| L&lt;sub&gt;b&lt;/sub&gt; | Gauge length                                                                | mm     |
| L&lt;sub&gt;c&lt;/sub&gt; | Parallel test length                                                       | mm     |
| L&lt;sub&gt;min&lt;/sub&gt; | Minimum length                                                             | mm     |</p>
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tr>
<td>$\lambda_i$</td>
<td>Length of each area with acceptable location of the fatigue pre-crack (given as SM ($\lambda$) = specified microstructure in ISO 15653)</td>
<td>mm</td>
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<tr>
<td>N</td>
<td>Number</td>
<td></td>
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<tr>
<td>$P_{cm}$</td>
<td>Cold cracking susceptibility</td>
<td>%</td>
</tr>
<tr>
<td>R</td>
<td>Transition radius</td>
<td>mm</td>
</tr>
<tr>
<td>$R_C$</td>
<td>Forming radius (inner radius of bends)</td>
<td>mm</td>
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<tr>
<td>$R_m$</td>
<td>Tensile strength</td>
<td>MPa</td>
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<tr>
<td>$R_e$</td>
<td>Yield strength (yield point)</td>
<td>MPa</td>
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<tr>
<td>$R_{el}$</td>
<td>Lower yield strength (yield point)</td>
<td>MPa</td>
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<tr>
<td>$R_{elH}$</td>
<td>Upper yield strength (yield point)</td>
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<tr>
<td>$R_p$</td>
<td>Yield strength (proof stress)</td>
<td>MPa</td>
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<tr>
<td>$R_{p0.2}$</td>
<td>Yield strength at 0.2% non-proportional elongation</td>
<td>MPa</td>
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<tr>
<td>$R_{p1.0}$</td>
<td>Yield strength at 1.0% total elongation</td>
<td>MPa</td>
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<tr>
<td>$R_s$</td>
<td>Transition radius</td>
<td>mm</td>
</tr>
<tr>
<td>$R_t$</td>
<td>Yield strength (proof stress), total elongation</td>
<td>MPa</td>
</tr>
<tr>
<td>$S_o$</td>
<td>The cross-sectional area of the test specimen in question</td>
<td>mm$^2$</td>
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<tr>
<td>$\Sigma$</td>
<td>Sum</td>
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<td>t</td>
<td>1) Thickness 2) Transverse direction</td>
<td>mm</td>
</tr>
<tr>
<td>$\nu$</td>
<td>Poisson’s ratio</td>
<td>-</td>
</tr>
<tr>
<td>V</td>
<td>Notch opening displacement</td>
<td>mm</td>
</tr>
<tr>
<td>$v_c$</td>
<td>Tensile test machine crosshead separation rate</td>
<td>mm/s</td>
</tr>
<tr>
<td>Z</td>
<td>Percentage reduction of area</td>
<td>%</td>
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</table>
Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16 000 professionals are dedicated to helping our customers make the world safer, smarter and greener.