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ECCC RECOMMENDATIONS - VOLUME 2 Part III [Issue 4]

TERMS AND TERMINOLOGY FOR POST SERVICE EXPOSED CREEP DATA

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TERMS AND TERMINOLOGY FOR POST SERVICE EXPOSED CREEP DATA

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ABSTRACT

ECCC Recommendations – Volume 2 Part III presents terms and terminology, with explanations, where required, related to post service exposed materials.

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FOREWORD

For “Post exposure data“ it is recognised that additional terms and terminology are required in addition to those in Part I.

- identify details associated with the state and location of sampling of post exposure material, i.e. material sampled from a component after a defined period of service.

- identify the service details of the sampled material.

- define the terminology related to the special testing techniques applied to post exposure material testing.

- define the particular terms used for the creep data assessment of post exposure material.

Section 1 defines the information required to characterise material sampled after service exposure including production details as well as the service conditions.

In Section 2 special testing techniques like Small Punch and Indention Creep Testing were added.

Section 3 includes test details (standards, environment, conditions and results) as particularly related to post exposure material testing.

Section 4 contains the units and symbols of the terms.

Section 5 contains definitions of terms used in data assessment.

SECTION 0

IDENTIFICATION OF SOURCE OF TEST RESULTS AND MATERIAL CODE

The following codes shall be used in sequence to form the full code for each (set of) test result(s).

0.1 Country Code - of origin of test result - select from Table 0.1

This code represents the country of the test result (Table 0.1) - the origin of the test material can be determined by reference to 1.2.1

0.2 Laboratory Code - select from Table 0.2

Lists produced by member(s) of the Management Committee are appended as Table 0.2. The test laboratory is defined as the location of the test data which may or may not be the same as the production source.

0.3 Material Code

<u>Virgin Material Code</u>

This represents the identification code used within each laboratory for each 'batch' of material tested and should be unique to each (set of) test result(s) from each laboratory. This could be the cast number of the melt, a code given by the laboratory etc. In special cases, the same code can be used by different laboratories provided that the material tested is the same in all aspects. The code used by each laboratory should allow the full manufacturing and thermo-mechanical and heat treatment history to be traceable within the organisation associated with that laboratory.

Example for virgin material

GB.02.3A3N

<u>Post Service Exposed Material Code</u>

For post service exposed material ".PE" should be added to the standard material code defined above.

Example for post exposed material

GB.02.3A3N.PE

SECTION 1

POST SERVICE EXPOSED (PE-) MATERIAL DETAILS

SCOPE - to identify the Post-service Exposed (PE-) material tested in terms of quality (material type), source, treatment(s) and supporting metadata

1.0 Material Origin

1.0.1 Plant type (power, chemical, petro-chemical, pharma, others)

1.0.2 Component

1.0.3 Characteristic dimensions (give details or approx. overall size)

1.1 Material Type

1.1.1 Broad Classification - select from Table 1.1

1.1.2 Alloy Name*

Generic material title, e.g. 2¼Cr1Mo

1.1.3 Specification and Grade Name*

Refers to the specification to which the material was produced, e.g. DIN EN 10216-2 and its grade name, e.g. X20CrMoV11-1

1.1.4 Trade or Proprietary Name*

* at least one of these items shall be supplied to identify the material tested

1.2 Material Source - specific to sampling position

1.2.1 Supplier/Material Manufacturer (and location)

The name of the organisation responsible for production of the primary melt to which the cast/heat number (1.2.2) is assigned. The (works) location at which this primary melt was produced shall be included in parentheses.

1.2.2 Cast/Heat Number

The numeric/alphanumeric reference identifying within the manufacturer's organisation (1.2.1) the primary melt from which the material tested originates

1.2.3 Batch Number

Refers to any sub-codes appended to cast/heat number used to identify a particular part of the primary melt, e.g. ingot number or strand number (and location within) for continuously cast production.

1.3 Manufacturing Details - specific to sampling position

1.3.1 Ingot or Continuous Cast

1.3.2 Cast/Heat Weight

Cast/Heat Weight of Primary Melt (1.2.2)

1.3.3 Ingot/Unit Weight

Individual ingot weight or lot weight of continuously cast product

1.4 Product Details - specific to sampling position

1.4.1 Product Form - select from Table 1.4.1

Record particular identifying number when different from 1.2.2.

1.4.2 Product Dimensions

Descriptive dimensions of product form in 1.4.1 stating, e.g. width, thickness, wall thickness, diameter etc.

1.4.3 Processing Route

For production of product in 1.4.1 from primary unit, e.g. ingot or billet.
Examples: rolling : forging : extruding etc.

1.5 Chemical Composition

1.5.1 Cast/Heat Composition of primary and/or secondary melt (1.3.1 or 1.3.3) 1.5.2 Product Composition of product form from which test specimens were prepared (1.4.1)	) Choose elements from Table 1.5

(It should be clearly stated whether composition quoted is for melt, i.e. 1.5.1 or for product, i.e. 1.5.2. When for the product and from particular location(s), this should be stated.)

NB: For chemical composition data particular to a location in a product, this should be indicated.

1.5.3 Nominal (if actual data not available)

1.6 Heat Treatment

1.6.1 Heat treatment details - temperature, time, cooling rate and coolant used - See Table 1.6.1

Location of heat treatment - state whether manufacturers works (see 1.4.1) or in laboratory

1.7 Sampled Material Details - the orientation and location of the sample from which test specimens are machined (see also comments in Section 3.1.2)

Material Details - a statement (or sketch) to identify the position and orientation of the sample from which test specimens are machined, e.g. rim of rotor in tangential direction. Alternatively, the information may also be provided as part of test specimen details if it relates more specifically to the test specimen, e.g. one quarter thickness and longitudinal with respect to a plate (see at 3.1.2)

1.7.1 Sampling method

1.7.2 Sample location (need reference to component geometry)

1.7.3 Sample size

1.8 Supporting or Metadata Data for Post Service Exposed (PE-) Material

1.8.0 Test piece identifier

This is a specific identifier for tensile test piece(s) when different or additional to the material code as defined in paragraph 0.3.

1.8.1 Tensile Properties

State test temperature(s) to which values in 1.8.1.1-1.8.1.7 apply.

1.8.1.1 Lower Yield Strength

1.8.1.2 Upper Yield Strength

1.8.1.3 0.2% Proof Strength

1.8.1.4 1.0% Proof Strength

1.8.1.5 Tensile Strength

1.8.1.6 Elongation

Value recorded should be referenced to the gauge length or $\sqrt{S_o}$ ratio over which it was measured.

1.8.1.7 Reduction of Area

1.8.2 Impact Properties

State form and size and notch type of specimen used, energy value recorded (indicate if normalised to a unit area value) and test temperature(s).

1.8.2.1 Room temperature impact value

1.8.2.2 Impact transition data

Transition Data - examples

- temperature for XX% brittle (^oC at %FA)
- temperature for specified energy value (^oC at J)

1.8.3 Hardness

State hardness test type

- H_V, H_B, R_C, R_B, other please specify

1.8.3.1 Following service

1.8.3.2 Post test

1.8.4 Grain Size

State whether ferrite or prior austenite grain size.

1.8.5 Microstructure

Either as resulting after the service exposure (i.e. prior to testing) (1.6. + 1.9, i.e. 1.8.5.1) or after testing i.e. 1.8.5.2. State main microstructural constituents and (approximate) volume fractions.

1.8.5.1 Following service

1.8.5.2 Post test

1.8.6 Damage following service

1.8.6.1 NDT-Results

Non Destructive Testing details about relevant component area and about the sampled material. State at least method(s) and result(s)

1.8.6.2 Metallography

(i) damage classification standard

(ii) results on sample or representative sections

(iii) results related to component in relevant area

In point (i) the cavity classification standard used should be stated (e.g. VGB–TW 507 or Nordtest), according to which the damage status is characterised. Point (ii) asks for metallographic information about the sample from which PE-creep tests were performed, or as an alternative – indications about a component area representative of the sample. Point (iii) relates to metallographic information on a significant area of a component, which is an area which is really threatened by creep damage the performance of which determines the actual remanant creep life.

1.9 Details on Service Conditions - related to sampling position

1.9.1 Stress (nominal or average, if available, and information about method or source of derivation, if known)

Information about source of derivation should explain by which method the stress given here was calculated (for instance van Mises reference stress, max. principal stress etc).

1.9.2 Temperature (nominal or average, if available, and information about method or source of derivation, if known)

Information about source should explain how the given temperature values were derived (for instance local measurement, design temperature, etc.).

1.9.3 Exposure Time

1.9.4 Safety factor in time

To be defined according specification or standard

1.9.5 Safety factor in stress

To be defined according specification or standard

Note: For a single component more than one set of stress, temperature and exposure time (see 1.9.1 to 1.9.3) may be needed.

SECTION 2

TEST TYPES

2.1 Stress Rupture Test

A test under constant load at a specified temperature until fracture occurs or test is discontinued.

The test may be carried out with a constant stress.

The measurements recorded shall be:-

(i) Hours elapsed either to fracture (B) or some shorter time designated as either most recent available duration (C) or time at which test is discontinued (UB).

(ii) Test Temperature - specified/measured/true.

(a) 'specified' = temperature selected for test.

(b) 'measured' = temperature shown by instrument/recording device.

(c) 'true' = estimate of the true test piece temperature, which is the measured temperature corrected for all systematic errors.

where all of these systematic errors are allowed for, by correction, in the recording system, then 'measured' = ‘true’.

(iii) Temperature Deviation = difference between any two temperatures and in particular:-

(a) 'total' = specified temperature - actual temperature.

(b) 'measured' = specified temperature - indicated temperature.

(iv) Elongation, over a specifiedlength, of fractured test piece.

(v) Reduction of area of fractured test piece.

(vi) Number of campaigns used during test = number of times the test piece is reloaded to the initial load/stress during the overall period of the test.

When the test is carried out using a notched test piece normally (iv) and (v) above will not apply.

A notched rupture test is similar to that for a stress to rupture test, except that the test piece used contains one or more circumferential notches, located in the parallel section; perpendicular to the applied load direction.

In the most common case of a single notch, this is placed usually in the middle of the parallel section of the test piece. Various notch types are available, e.g. V-notch and the Bridgman or semi circular notch. The V-notch which is the most commonly used, is described by two diameters, that of the parallel section and at the root of the notch, the radius at the root of the notch, and the notch angle - see Figure 3.2. The diameters, the notch angle and the notch root radius are used to determine the elastic stress concentration factor (see Section 4.4.1).

The number of notches, the notch type used and relevant dimensions must be reported.

2.2 Creep Rupture Test

As per stress rupture test with measurement of extension as a function of test duration over a specified gauge length. (See also 2.3 Creep Test.) Strain values are calculated using the extension measurements and the reference length - see 3.3.2(i)-(iii) and Volume 3 Part I.

2.3 Creep Test

A test carried out either under constant load or constant stress, at a specified temperature, to determine the time dependent increase in strain, Fig. 2.1 (i). If the test proceeds to fracture, it shall be classified as a creep rupture test - 2.2 above. The increase in displacement as a function of time may be measured either by an extensometer or by removing the test piece from the test machine at intervals to carry out measurements at room temperature - in both cases over a specified length.

Measurement of displacement (see 2.2) during a creep test by means of an extensometer shall be deemed an 'uninterrupted test', even though the actual values may be taken only at selected intervals during a campaign. An 'uninterrupted' test may be made up of several campaigns - see 2.1(vi).

Measurement of displacement after removal of the test piece from the test machine shall be deemed an 'interrupted test' (see 2.2).

There are four phases to an uninterrupted creep test during which measurements are made viz:-

(i) Set up or cold loading phase at room temperature.

(ii) Loading phase at test temperature.

(iii) Creep test phase.

(iv) Unloading phase with intermediate or final unloading for the determination of back displacement corresponding to ($\varepsilon_e + \varepsilon_k$).

In the interrupted creep test the permanent strain ε_{per} is measured. In the uninterrupted test ε_p or ε_f (and ε_i) are measured in the usual case.

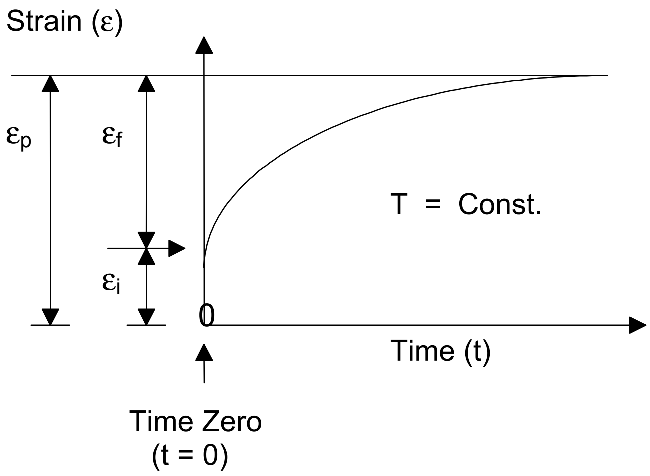
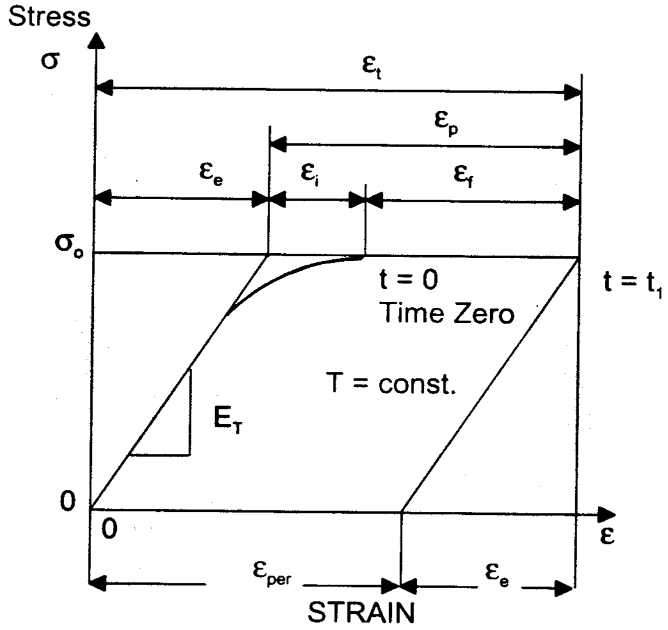


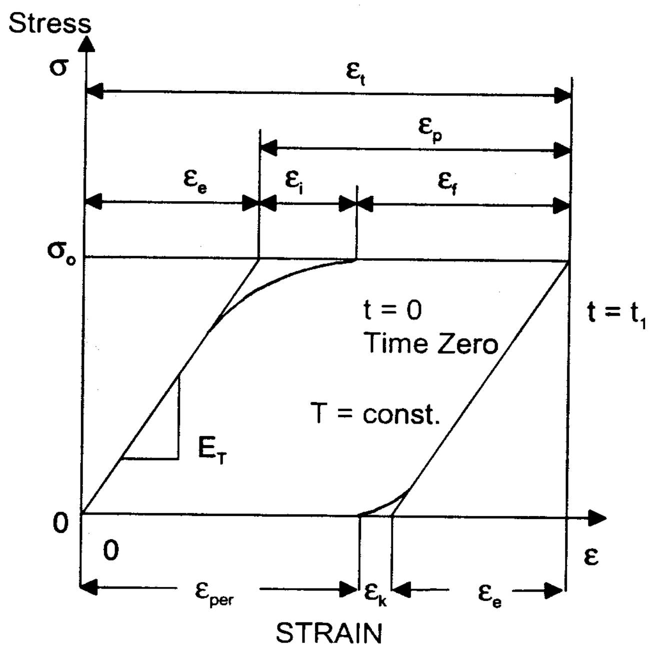
Fig. 2.1 (i) CREEP CURVE (see 2.3)

Fig. 2.1 (i) to (iii) and Section 4 define various measurements which are required to be made. With particular reference to the uninterrupted test, the elastic modulus, E, can be measured and recorded at room temperature on the creep test piece (phase (i)) or be obtained from another source, e.g. tensile test on the same or related batch of material or from published data for the material type (Table 1.1) tested. For both uninterrupted and interrupted tests, elastic modulus values $E_{T(S)}$ and initial plastic strain ε_i, may also be recorded at the test temperature as part of the loading phase (phase (ii)) - Fig. 2.1 (iii). $E_{T(S)}$ can be also determined in phase (iv). Further, $E_{T(S)}$ and ε_i may be determined in a hot tensile test performed on the same batch of material with similar loading rate as in phase (ii) of the creep test.

In the normal case the anelastic strain ε_k is relatively small and therefore may be neglected, thus $\varepsilon_p \approx \varepsilon_{per}$ (Fig. 2.1(ii)). However, if ε_k is not neglected $\varepsilon_p = \varepsilon_{per} + \varepsilon_k$ (Fig. 2.1(iii)). In this case, to relate the results from interrupted and uninterrupted tests, note needs to be taken of the parameter ε_k.



(ii)



(iii)

FIG.2.1: STRESS STRAIN CURVE FOR CREEP WITH (ii) AND WITHOUT (iii) NEGLIGIBLE ANELASTIC STRAIN ε_K

(see next page for list of descriptors used in Fig.2.1)

Fig. 2.1 - DESCRIPTORS

$E_{T(S)}$	-	Static Elastic Modulus at test temperature
σ_o	-	Applied stress*
ε_t	-	Total strain
ε_f	-	Creep strain
ε_p	-	Total plastic strain (non proportional strain)
ε_{per}	-	Permanent strain
ε_i	-	Initial plastic strain
ε_e	-	Elastic strain
ε_k	-	Anelastic strain (recovery strain)
Time Zero, t = 0	-	Start of creep test (phase (iii))
Initial Total Strain (ε_o)	=	$\varepsilon_e + \varepsilon_i$
Total Strain (ε_t)	=	$\varepsilon_o + \varepsilon_f$
Total Plastic Strain (ε_p)	=	$\varepsilon_i + \varepsilon_f$
Total Back Strain	=	$\varepsilon_e + \varepsilon_k$ (measured after unloading (phase (iv)) of the uninterrupted test)

*Stress applied to initial cross section measured at room temperature

The tests described in chapters 2.1 to 2.3 were performed on specimens, whose geometry meets the requirements according to Tables 5a and 5b of Volume 3 part I.

If the tests were performed on specimens, which are smaller then those defined in Tables 5a and 5b of Volume 3 part I, the test will be called small scale or miniature specimen tests (see also Volume 3 part III Section 3).

2.4 Small Punch testing

In a small punch test a loaded punch is pushed through a thin disc specimen of test material. The sample is either simply supported or clamped between two dies and a cylindrical punch is led into concentric holes in the upper and lower dies and through the tested material (Fig. 2.2). During the test the loading remains constant. The typical diameter of the small disc is 8 - 10 mm, the thickness 0,25 - 0.5 mm, the punch diameter 2 mm or 2.5 mm and the typical diameter of the hole in the lower die is 4 mm. Due to the fact that the thin sample is loaded at high temperature, it may be necessary to use a protective atmosphere e. g. argon. As with creep tests with measured deformation, it is necessary to continuously record the displacement of the punch during testing.

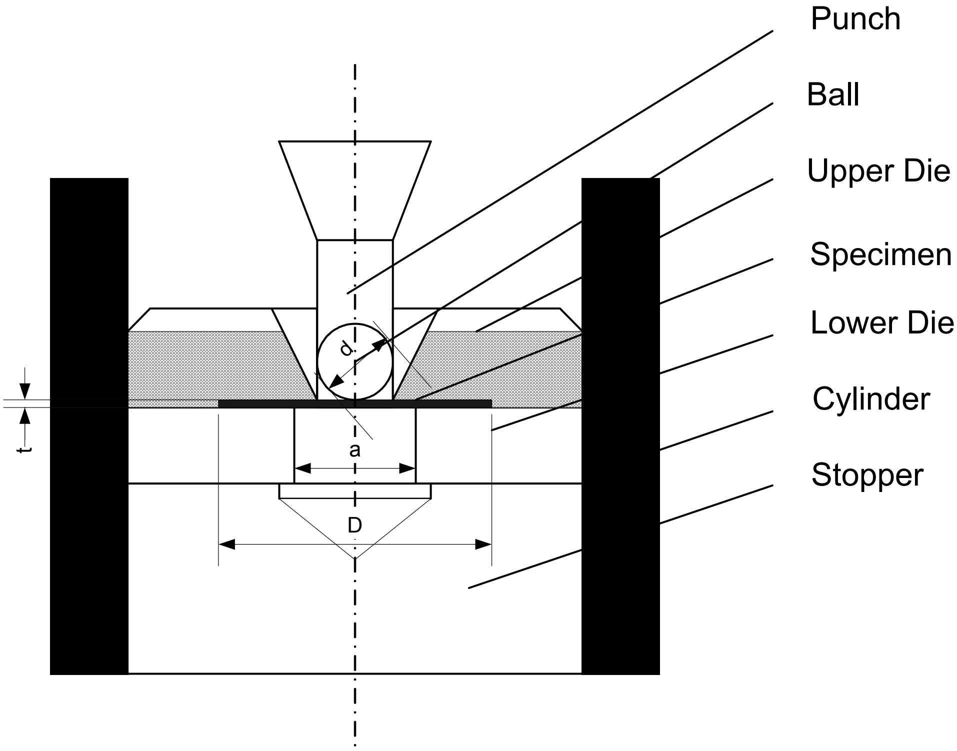


FIG 2.2: SCHEMATIC SKETCH OF SMALL PUNCH TEST

2.5 Impression Creep Testing

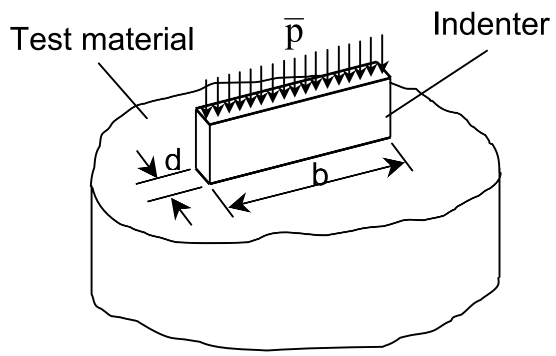
The impression creep testing technique involves the application of a steady load to a flat-ended indenter, placed on the surface of a material at elevated temperature. The displacement-time record from such a test is related to the creep properties of a relatively small volume of material in the immediate vicinity of the indenter. The indenter can be cylindrical or rectangular, and for these types of indenters, it has been shown that the reference stress approach can be used to convert the mean pressure under the indenter, $\bar{p}$, to the corresponding uniaxial stress, σ, i.e.

$$\sigma = \eta\bar{p}$$

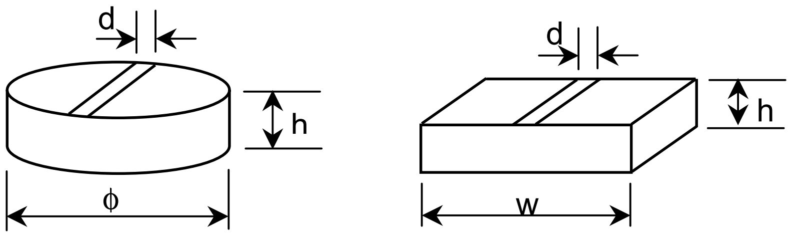
and to convert the creep displacement, Δ^c, to the corresponding uniaxial creep strain, ε_f, i.e.

$$\varepsilon_f = \frac{\Delta^c}{\beta d}$$

where η and β are geometrical conversion parameters and d is the diameter of the cylindrical indenter or the thickness of the rectangular indenter, see Figure 2.3.



(a) schematic diagram of impression creep test with a rectangular indenter



(b) cylindrical specimen (c) square specimen

FIG. 2.3: IMPRESSION CREEP TESTING AND TEST SPECIMENS

SECTION 3

TEST DETAILS

SCOPE - to define the details required to describe fully the test carried out.

3.0 Test Standard

State testing standard used (see Vol. 3 Part I - Table 3) or describe procedure.

3.1 Testpiece Details

3.1.1 Test piece details (full-size, sub-size, miniature)

A full-size specimen is considered a specimen satisfying all requirements as given in Volume 3, Part I, Table 3, i.e. the diameter of the cylindrical length is bigger than 5 mm.

On a subsize specimen the diameter of the cylindrical length is between 5 and 3 mm. Miniature specimens, typically machined from samples cut by "semi-non destructive methods" from components, have diameters in the cylindrical length smaller than 3 mm down to ca. 0.8 mm. Smaller sizes than these are considered for small scale, small punch and impression creep testing.

3.1.2 Test piece identifier.

3.1.3 Location and direction of test piece in products (see 1.4.2).

The following terms shall be recognised to describe the orientation of the axis of the test piece with respect to the product (Section 1.4), i.e. the relevant component area, from which it is sampled.

(i) Longitudinal (L) - test piece axis is parallel to the major working direction of the product. This can be determined by macroscopic grain flow if not known from information received.

(ii) Transverse (Tr) - test piece axis is normal to the major working direction in the plane of the product.

(iii) Through Thickness (TT) - test piece axis is orientated through the thickness of the product, normal to the plane of the product.

Other terms which may be used, e.g. axial, tangential and circumferential are considered to be special cases of (i) and (ii) above. When such terms are used they should be accompanied by a descriptive diagram to show exact location and direction.

Because of the wide variety of potential applications for small scale testing it may not be possible to define small specimen orientation with respect to the sampled component in a way which will be meaningful in all situations. It should be noted that, whereas in conventional uniaxial specimens material deforms in the direction of the loading axis, this is not the case for disc specimens.

It is important therefore that the orientation of the plane of the sampled disc is defined with respect to the component or microstructure from which the sample is taken. In the case of impression creep testing, where rectangular indenters can be used, further definition of testing orientation within the disc may be necessary.

3.1.4 Dimensions and type of test piece tested (see also Section 4).

(i) Parallel length and diameter (or section).

(ii) Gauge length used (extensometer length).

(iii) Reference length - see Figs.3 and 3.1 on page 3.3.

(iv) Type and dimensions of notch (when used) - see examples in Figs.3.2 and 3.3 on page 3.4.

(v) Transition radius.

(vi) Special features of test piece, e.g. combined plain and notched; extensometer location ridges, etc.

(vii) Special/particular test piece form used (as drawing provided), e.g. tubular, double diameter welded specimen, small punch and indention creep specimen etc. (when applicable)

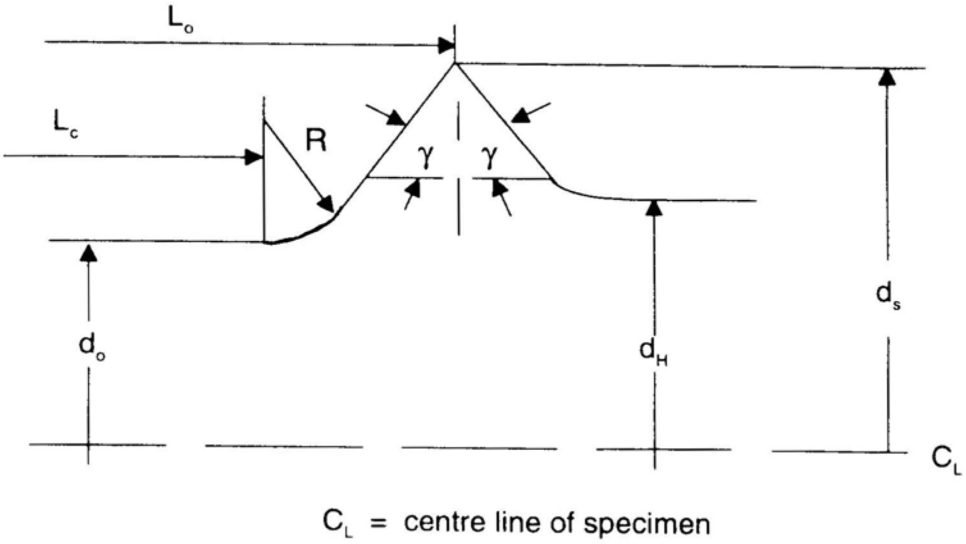
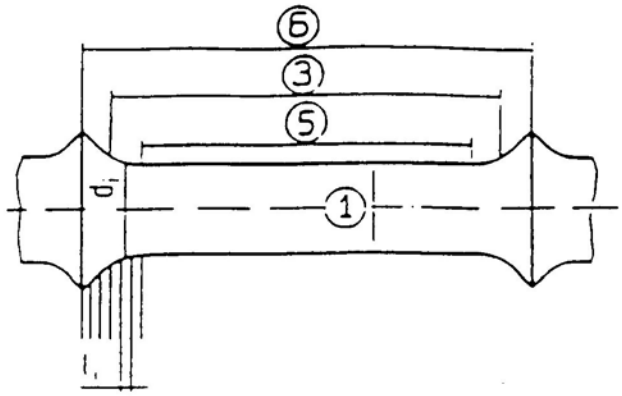


FIG.3: DIMENSIONS OF RIDGED SPECIMEN FOR DETERMINATION OF REFERENCE LENGTH



$L_r = L_c + 2\sum_i\left[(d/d_i)^{2n} l_i\right]$ if the value of n is not known, n = 5

where n = creep exponent

FIG.3.1: CALCULATION OF REFERENCE LENGTH

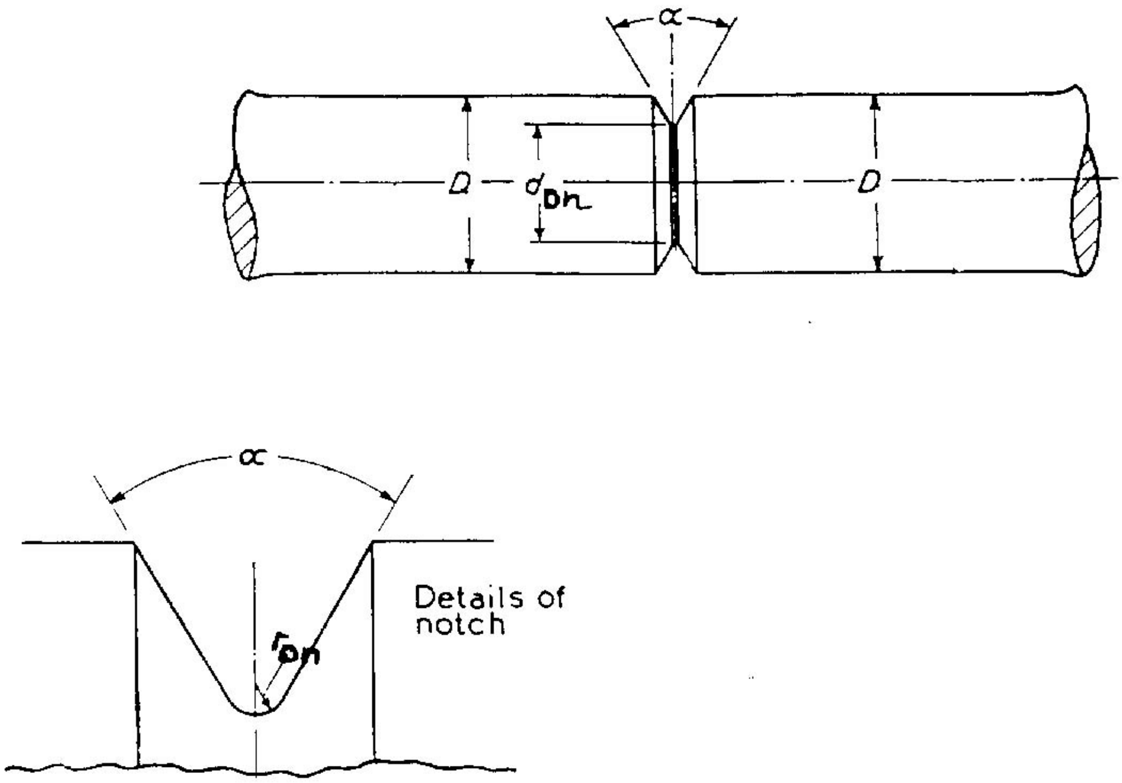


FIG.3.2: EXAMPLE OF V-NOTCHED TEST PIECE OF CIRCULAR CROSS SECTION

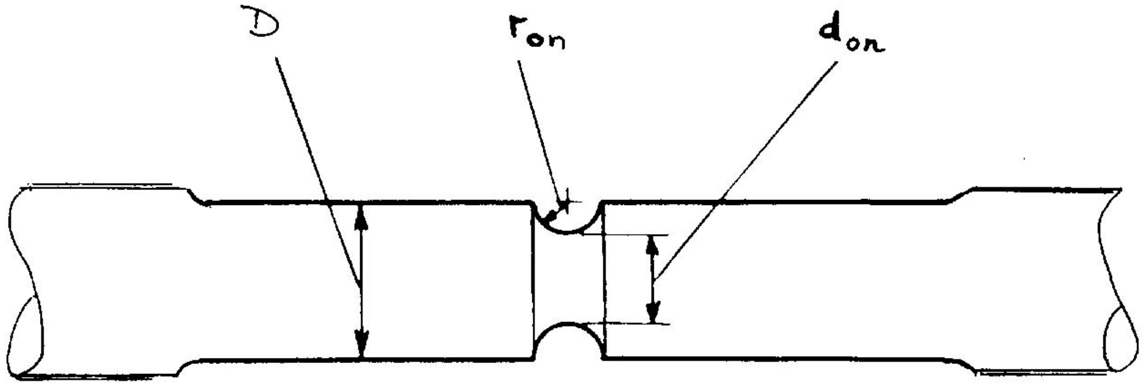


FIG.3.3: EXAMPLE OF “BRIDGEMAN” TYPE NOTCHED TESTPIECE

3.2 Test Conditions

3.2.1 Temperature

(i) Specified value and units.

(ii) Actual value and range achieved.

(iii) Heating rate or heating time.

(iv) Soak period before load applied.

(v) Cooling rate or cooling time at end of each campaign (Vol.2 Part I, 2.1(vi)) and/or end of test or state normal laboratory practice, e.g. cooled in still air.

(vi) Laboratory temperature control limits

(vii) Thermocouple type used.

(viii) Thermocouple calibration - errors

- total error
- systematic error
- uncertainty

The total temperature error is the difference between the indicated temperature and the true temperature of a thermocouple. This error contains systematic and random components.

(a) Systematic Error

The systematic error can be determined during the calibration of a thermocouple. It is the mean of repeated measurements of the difference between the indicated temperature and the true temperature of the thermocouple. For a discussion on parameters which determine the magnitude of this error, see Volume 3, Part I, Appendix 1, Section 2.3.

The systematic error of a thermocouple may be accounted for in the overall temperature measurement system so that the indicated temperature equates to the true temperature, at the point of measurement, except for any uncertainty.

(b) Uncertainty

Associated with all physical measurements there is some level of uncertainty, deriving from the natural scatter in results at each stage of measurement. For thermocouple calibrations there may be several measurement stages between the national standard and the working thermocouple. An 'error budget' should be calculated to estimate the uncertainty associated with the working thermocouple, expressed as $\pm$ X °C.

A procedure for estimating uncertainty for temperature measurements from thermocouples is included in Volume 3, Part I, Appendix 1.

3.2.2 Stress/Load and Strain

(i) Applied stress or initial stress (σ_o).

(ii) Extensometer

- type (single or double sided)
- means of location on specimen
- calibration details
- gauge length

3.2.3 Machine Details

(i) Machine type

(ii) Number of strings in machine

(iii) Number of test pieces per string

3.2.4 Load Measurement System

3.2.5 Load Calibration

3.2.6 Atmosphere used (if not air)

3.3 Test Results

3.3.1 All Test Types

(i) Test duration (t).

- as per (iii) below
- as per 3.3.2 (iv) or 3.3.2 (v)

(ii) Number of campaigns/interruptions (see section 2.1(vi))

(iii) Current test condition (choose one).

- test continuing (C)
- fractured (B)
- discontinued (UB)

*(iv) Ductility value

- elongation (A_u)
- reduction of area (Z_u)
- at notch plane (Z_{un})

*(v) Position of fracture in parallel or gauge length of plain testpiece.

*Does not apply for creep tests, i.e. those not taken to rupture.

3.3.2 Creep Tests

(i) Initial plastic strain

(ii) Creep strain (ε_f) at 3.3.1 (i)

(iii) Total plastic strain (ε_p) at 3.3.1 (i)

**(iv)Time to specific creep strain.

**(v) Time to specific plastic strain

**(vi) Stress to a specific creep strain.

**(vii) Stress to total plastic strain.

3.3.3 Quality of Testing

All defects in specimens or testing which are considered to be non-standard, e.g. temperature fluctuations outwith specified and/or control bands, or to have an influence on the results of the test, e.g. specimen defect revealed only after testing, shall be recorded and referenced to the particular specimen (or specimens where the defect is general to a string of tests or furnace load).

** These are assessed results - see section 4.6

SECTION 4

STANDARD TERMS AND SYMBOLS

NAME	UNIT(S)	SYMBOL
4.1 Manufacture (Section 1.3)		
See Table 1.3.1 for descriptors and symbols for material production.		
Ingot Cast	-	I
Continuous Cast	-	C
Cast/Heat/Ingot/Unit Weight	-	kg
Product Dimensions (1.4)	mm	mm
4.2 Chemical Analysis (Section 1.5)		ISO TR6306:1989 (BS6200 Part 4)
See Table 1.5 and report Elements in order as given	wt%	
4.3 Test Material Processing and Background/ Metadata Data (Sections 1.6 and 1.7)		
Heat Treatment		
Temperature	Degree Celsius (^oC)	T
Time	Hours (h)	t
Cooling Rate (also for Heating Rate - see 3.2.1 (iii))	$^oC/h$	
Air Cooled	( )	AC
Oil Quenched	( )	OQ
Water Quenched	( )	WQ
Water Spray	( )	WSQ
Furnace Cooled	( )	FC
Annealed	( )	A
Tensile Properties (Vol.2 Part I 1.8.1 and Part III 1.8.1)		
Test temperature	°C	
0.2% Proof Strength	MPa	$R_{p0.2}$
0.2% Proof Strength of post-exposure material	MPa	$R_{p0.2\text{-}PE}$
Yield Strength	MPa	R_e
- upper	MPa	R_{eH}
- lower	MPa	R_{eL}
X% Proof Strength	MPa	R_{pX}
X% Proof Strength of post-exposure material	MPa	$R_{pX\text{-}PE}$
Tensile Strength	MPa	R_m
Tensile Strength of post-exposure material	MPa	$R_{m\text{-}PE}$
Elongation After Fracture	%	A
Elongation After Fracture of post-exposure material	%	A_{PE}
Reduction of Area After Fracture	%	Z
Reduction of Area After Fracture of post-exposure material	%	$Z_{\text{-}PE}$

NAME	UNIT(S)	SYMBOL
Impact Properties (1.8.2)		
Type of Specimen and Notch Form		V or U as subscript
Energy Absorbed of post-exposure material	Joule	$C_{v\text{-}PE}$
Energy/Unit Area	Joule/mm^2	$A_{v\text{-}PE}$
Transition Data	°C at % FA	FATT$\%_{\text{-}PE}$
	°C at J	TTj$_{\text{-}PE}$
Hardness (1.8.3)		
Vickers	Hardness Number and Load Used	eg HV30
Brinell	Hardness Number	HBS (steel ball) HBW (WC ball)
Rockwell	Hardness Number and Indenter type	R_c or R_B
Grain Size (1.8.4)		
Ferrite	mm	di (mean linear intercept)
Prior Austenite	ASTM Grain Size No.	Grain Size No.
Microstructure (1.8.5) - see note (Phases present as %)		
Ferrite	%	Ferrite
Austenite	%	Austenite
Bainite	%	Bainite
Martensite	%	Martensite
Pearlite	%	Pearlite
Carbide Type	%	(type to be indicated)
Sigma Phase	%	Sigma (estimated)
Laves Phase	%	Laves (estimated)

Note

For the microstructure determined (and phases present), it is required that it should be stated whether this was determined from the heat treated product (see 1.6) or from a simulation heat treatment applied for the test piece material.

Service conditions (see 1.9)

Service temperature	°C	T_{PE}
Service time	h	t_{PE}
Service stress	MPa	σ_{PE}
Safety factor in time		K_t
Safety factor in stress		K_σ

NAME	UNIT(S)	SYMBOL
4.4 Test Details		
4.4.1 Test Piece (Section 3.1)		
a. Conventional or small scale conventional test		
Initial diameter of cross section of the parallel length of a cylindrical test piece	mm	d_o
Instantaneous diameter	"	d
Final diameter within necked region or after fracture	"	d_u
Thickness	"	a
Width	"	b
Diameter of tubular specimens	"	o.d. i.d.
Diameter of barrel behind ridge/collar (Fig. 3)	"	d_H
Diameter at ridge/collar tip (Fig. 3)	"	d_s
Angle of ridge/collar (Fig. 3)	degree (°)	γ
Original Gauge Length	mm	L_o
Parallel (or cylinder) Length	"	L_c
Extensometer Gauge Length	"	L_e
Reference Length	"	L_r
Transition Radius to Grip End	"	r
Cross section Area at Notch Root	mm²	S_{on}
Initial Notch Root Radius	mm	r_{on}
Initial Diameter at Notch Root	mm	d_{on}
Final Diameter at Notch Root	mm	d_{un}
Notch Angle		α
Elastic Stress Concentration Factor for Notched Test Piece		K_t
Directionality		
Longitudinal	-	L
Transverse	-	Tr
Through Thickness	-	TT
Location in Test Material*		
Axial/Centre/Core		
Mid Radial		
.		
b. Small punch test (Fig. 2.2)		
Ball diameter	mm	d
Specimen diameter	mm	D
Hole diameter	mm	a
Initial specimen thickness	mm	t
c. Impression creep test (Fig. 2.3)		
Indenter dimensions in Impression Creep Test	mm	d, b
Diameter of disc specimen	mm	Φ
Width of square specimen	mm	w
Thickness of specimen	mm	h

4.4.2 **Machine Details** (see 3.2.3)

4.4.2.1 Type (3.2.3 (i))

SE	:	Servo electrical
SH	:	Servo hydraulic
DW	:	Dead weight - includes lever loaded
SM	:	Servo mechanical
SP	:	Small Punch
IC	:	Impression Creep

4.4.2.2 Load Application and Measurement (3.2.4)

W	:	Direct application of weights
L	:	Application of load via calibrated lever system
LC	:	Load cell with electronic or electrical conditioning and indication

NAME	UNIT(S)	SYMBOL
4.5 Test Results (Section 3.3)		
Test Temperature	Degree Celsius (°C)	T
Thermocouple Type	Code	Code Letter e.g. 'R'
Initial or Applied Stress or Stress at Time Zero	MPa	σ_o
Initial or Applied Load	N	F
Test continuing	-	C
Test broken	-	B
Test discontinued	-	UB
Elastic Modulus		
- at RT (static modulus)	GPa	E_S
- (dynamic modulus)	GPa	E_D
- at T (static modulus)	GPa	$E_{T(S)}$
- (dynamic modulus)	GPa	$E_{T(D)}$
Strain (see Part I, Fig. 2.1)		
Elastic		ε_e
Initial Plastic		ε_i
Total Plastic		ε_p
Creep		ε_f
Total Initial		ε_o
Total		ε_t
Anelastic (e.g. Part I, Fig. 2.1 (ii))		ε_k

Displacement in Small Punch Test (Fig. 2.2)	mm	δ
Creep displacement in Impression Creep Test (Fig. 2.3)	mm	Δ^c
Geometrical conversion parameters		η,β
Creep Strain Rate (PE-material)	h^{-1}	$\dot{\varepsilon}_{f-PE}$
Minimum Creep Strain Rate (PE-material)	h^{-1}	$\dot{\varepsilon}_{f-PE}$ (min)
Time Zero	h	t_o
Test Duration (since time zero)	h	t
Creep Rupture Time - plain test piece, virgin material	h	t_u
- plain test piece, PE-material		$t_{u\text{-}PE}$
Time to Creep Strain (PE-material)	h	$t_{f\varepsilon-PE}$ *(1)
Time to Total Plastic Strain (PE-material)	h	$t_{p\varepsilon-PE}$ *(1)
Time to X% (PE-material)	h	$t_{x\text{-}PE}\%$
Elongation at Rupture (PE-material)	%	$A_{u\text{-}PE}$
Reduction of Area at Rupture (PE-material)	%	$Z_{u\text{-}PE}$

(1) The symbol ε in this case represents digit(s) indicating the amount of strain in % e.g. 0.2.

4.6 Assessed Results

Assessed results are those results derived by calculation/interpolation from the test results obtained on post exposure material. In addition to the main symbol for each type of assessed result, designations for time (t) and temperature (T) are added to define the conditions applying for the particular assessed result.

The following terms and symbols thus apply:-

NAME	UNIT(S)	SYMBOL
Rupture Strength (PE-material)	MPa	${}_{PE}R_{u/t/T}$
Strength for Specific Creep Strain (PE-material)	MPa	${}_{PE}R_{f\varepsilon/t/T}$
Strength for Specific Plastic Strain (PE-material)	MPa	${}_{PE}R_{p\varepsilon/t/T}$
Predicted Time to Rupture (PE-material)	h	$t_{u\text{-}PE}$*
Predicted Time to Specific Creep Strain (PE-material)	h	$t_{f\varepsilon\text{-}PE}$*
Predicted Time to Specific Total Plastic Strain (PE-material)	h	$t_{p\varepsilon\text{-}PE}$*
Target Residual Life	h	t_{RL}
Estimated Stress that will produce rupture at Target Residual Life	MPa	σ_{RL}*

SECTION 5

5.1 DATA ASSESSMENT - DEFINITIONS OF TERMS

CRDA	creep rupture data assessment
CSDA	creep strength data assessment
SRDA	stress relaxation data assessment
PAT	post assessment test
t_r*	predicted rupture time
$t_{f\varepsilon}$*	predicted time to specific creep strain
$t_{p\varepsilon}$*	predicted time to specific total plastic strain
$t_{r[max]}$	the time of the longest duration (T, σ, t) data co-ordinate
$t_{r[min]}$	the time of the shortest duration (T, σ, t) data co-ordinate
T_{max}	the highest temperature for which data have been collected
T_{min}	the lowest temperature for which data have been collected
T_{main}	the temperature with the largest number of data points
$T_{max[10\%]}$	the highest temperature for which there are greater than 10% data points
$T_{min[10\%]}$	the lowest temperature for which there are greater than 10% data points
n	the stress index in the expression $\varepsilon = C\ \sigma_o^n$, where C is constant for a given material and temperature (usually n is used with reference to the minimum creep rate, i.e. $\varepsilon_{min} = C\ \sigma_o^n$ - "Norton's Law")
$n_{f\varepsilon}$	the slope of log $t_{f\varepsilon}$ versus log σ_o for a given σ_o, i.e. $n_{f\varepsilon} = -\partial(\log t_{f\varepsilon})/\partial(\log \sigma_o)$
$n_{p\varepsilon}$	the slope of log $t_{p\varepsilon}$ versus log σ_o for a given σ_o, i.e. $n_{p\varepsilon} = -\partial(\log t_{p\varepsilon})/\partial(\log \sigma_o)$

n_r	the slope of log t_r* versus log σ_o for a given σ_o, i.e. $n_r = -\partial(\log t_r^*)/\partial(\log \sigma_o)$
$\sigma_{o[max]}$	the highest stress for which data exists in the data set
$\sigma_{o[min]}$	the lowest stress for which data exists in the data set
A-SRLT	residual log time divided by the standard deviation for all the n_A residual log times at all temperatures, i.e. A-SRLT = $\{(\log t_r - \log t_r^*)\}/s_{[A\text{-}RLT]}$
I-SRLT	residual log time divided by the standard deviation for all the n_I residual log times at the temperature of interest, i.e. I-SRLT = $\{(\log t_r - \log t_r^*)\}/s_{[I\text{-}RLT]}$
$S_{[A\text{-}RLT]}$	standard deviation of all the n_A residual log times at all temperatures, i.e. $S_{[A\text{-}RLT]} = \sqrt{\{\Sigma_i (\log t_{ri} - \log t_r^*{}_i)^2/n_A - 1)\}}$, where i = 1, 2, ... n_A
$S_{[I\text{-}RLT]}$	standard deviation for all the n_I residual log times at the temperatures of interest, i.e. $S_{[I\text{-}RLT]} = \sqrt{\{\Sigma_i (\log t_{rj} - \log t_r^*{}_j)^2/n_A - 1)\}}$, where j = 1, 2, ... n_I
RLA	Residual Life Assessment: All activities needed to establish the further exploitability of a given target component
Reference material	Material which is suitable to be used for comparison with a weld or a PE material
Reference Curve	Mathematical model describing the creep behaviour of a reference material
PE	Post exposure
LDAR	Linear damage accumulation rule
CSC	Concept of similar curves
CRL	Computation of residual life

TABLE 0.1

COUNTRY CODES

COUNTRY NAME	BS EN ISO 3166-1:1998 CODE
Australia	AU
Austria	AT
Belgium	BE
Canada	CA
China	CN
Cyprus	CY
Czech Republic	CZ
Czechoslovakia *	CS
Denmark	DK
Estonia	EE
Finland	FI
France	FR
German Democratic Republic *	DD
German Federal Republic *	DE
Germany	DE
Greece	GR
Greenland	GL
Hungary	HU
Iceland	IS
India	IN
Ireland	IE
Italy	IT
Japan	JP
Latvia	LV
Liechtenstein	LI
Lithuania	LT
Luxembourg	LU
Malta	MT
Monaco	MC
Netherlands	NL
Norway	NO
Poland	PL
Portugal	PT
Romania	RO
Russia	RU
Slovakia	SK
Slovenia	SI
South Africa	ZA
Spain	ES
Sweden	SE
Switzerland	CH
United Kingdom	GB
United States	US
USSR *	SU
European Union	EU

* Country name no longer in use

TABLE 0.2
LABORATORY CODES

Country	Code	Laboratory : Place
Austria	AT.01	Voest Alpine Stahl Linz GmbH : Linz
	AT.02	Böhler Edelstahl GmbH : Kapfenberg
	AT.03	Schoeller-Bleckmann : Ternitz
	AT.04	Metallwerk Plansee GmbH : Reute
	AT.05	Österr. Forschungszentrum Seibersdorf GmbH : Seibersdorf
	AT.06	Abt. Werkstoffkunde u. Schweibtechnik Technische Universität Graz : Graz
	AT.07	Inst. f. Metallkunde u. Werkstoffprüfung, Montanuniversität Leoben : Leoben
	AT.08	Inst. f. Werkstoffkunde u. Materialprüfung, TU Wien : Wien
	AT.09	Inst. f. physkal. Chemie, Uni Wien : Wien
Belgium	BE.01	Laborelec : Linkebeek
	BE.02	Belgian Welding Institute : Ghent
Denmark	DK.01	Forskningscenter RISØ : Roskilde
Czech Republic	CZ.01	Vitkovice – R&D : Ostrava - Vitkovice
	CZ.02	SVUM : Prague
Finland	FI.01	VTT : Helsinki
France	FR.01	Vallourec
	FR.02	ALSTOM Power (Stein Industrie)
	FR.03	Aubert et Duval
	FR.04	SERMA Belfort
	FR.05	Electricité de France
	FR.06	CEA : Saclay
Germany	DE.01	Institut für Werkstoffkunde : Darmstadt
	DE.02	Staatl. Materialprüfungsanstalt : Stuttgart
	DE.03	Siemens AG : Mülheim
	DE.04	ALSTOM Power (ABB Kraftwerk AG) : Mannheim
	DE.05	Salzgitter Mannesmann Forschung : Duisburg
	DE.06	ALSTOM Power (ALSTOM Energie) : Nurnberg (formerly MAN Energie)
	DE.07	Arbeitsgemeinschaft für Warmfeste Stähle
	DE.08	Siempelkamp Prüf- und Gutachter-Gesellschaft : Dresden
Great Britain	GB.01	ERA Technology Ltd. : Leatherhead
	GB.02	Corus (British Steel), Swinden Technology Centre : Rotherham
	GB.03	ALSTOM Power (ALSTOM Energy) : Rugby (formerly GEC Alsthom)
	GB.04	Bodycote : Newcastle upon Tyne (formerly Rolls Royce IRD)
	GB.05	Mitsui Babcock Technology ; Renfrew
	GB.06	Incotest : Hereford
	GB.07	National Engineering Laboratory : East Kilbride
	GB.08	Serco, Warrington
Italy	IT.01	Centro Sviluppo Materiali SpA : Roma
	IT.02	Istituto Scientifico Breda : Milano
	IT.03	Dalmine Laboratory Service : Dalmine (BG)

	IT.04	CESI : Piacenza
	IT.05	CNR-IENI : Cinisello Balsamo (Mi)
	IT.06	Ansaldo GIE : Legnano (Mi)
	IT.07	ENEA CRE Casaccia : Roma
	IT.08	ENEL DSR : Milano
	IT.09	Nuovo Pignone : Firenze
	IT.10	CESI (CISE) : Segrate (Mi)
	IT.11	Università Politecnico delle Marche : Ancona
	IT.12	Avio : Torino (former FIAT Avio)
	IT.13	Falck Servizi - Sesto San Giovanni (Mi)
	IT.14	Societa Italiana Acciai per Utensili (SIAU)
	IT.15	Politecnico di Milano
Netherlands	NL.01	TNO-Metals Research Institute : Apeldoorn
	NL.02	DSM Services : Geleen
Portugal	PT.01	Instituto de Soldadura e Qualidade (ISQ)
Slovakia	SK.01	VUZ-PI SR: Bratislava
Sweden	SW.01	KIMAB : Stockholm (formerly SIMR)
	SW02	Outokumpu Stainless : Avesta
	SW03	Sandvik Materials Technology : Sandviken
Switzerland	CH.01	ALSTOM Power (ABB Power Generation Ltd) : Baden
	CH.02	Sulzer Innotec AG : Winterthur
European Union	EU.01	CEC Joint Research Centre : Petten

NOTE

For laboratories supplying data which are not included in the above list, please apply to the editor of this document for an appropriate Code.

TABLE 1.1

MATERIAL TYPE CLASSIFICATION

CARBON	(Mn ≤0.8%)
CARBON-MANGANESE	(Mn >0.8≤2.0%)
MICROALLOYED	
LOW ALLOY FERRITIC	(Cr≤5%)
HIGH ALLOY FERRITIC	(Cr >5≤13% + alloys of Mo, V, Nb etc.)
AUSTENITIC STAINLESS	
FERRITIC STAINLESS	
DUPLEX STAINLESS	
NICKEL BASE	

TABLE 1.3.1

MELTING PROCESS DETAILS

A PRIMARY MELTING

Open Hearth	(OH)
Basic Open Hearth	(BOH)
Acid Open Hearth	(AOH)
Electric Arc (state if not basic)	(EA)
Basic Oxygen	(BOF)
Argon Oxygen Decarburisation	(AOD)
Induction Melted	(IM)
Laboratory (induction) Melted	(LM)
Vacuum Induction Melted	(VIM)
Ladle Refined	(LR)

B DEOXIDATION IN PRIMARY MELT

Rimmed Steel	(R)
Semi Killed	(SK)
Fully Killed	(FK)
Aluminium Deoxidised	(A)
Silicon Deoxidised	(S)
Vacuum Carbon Deoxidised	(VCD)

C SECONDARY MELTING

Remelted	(R)
Vacuum Arc Remelted	(VAR)
Electro (Slag) Flux Remelted	(EFR)

TABLE 1.4.1

PRODUCT FORM

BAR (ROD) - produced by longitudinal rolling or forging

PLATE

FORGING

TUBE (o.d. $\leq$75 mm)

PIPE (o.d. >75 mm)

SHEET

STRIP

WIRE

CONCAST PRODUCT

CASTING

TABLE 1.5

REPORTING OF COMPOSITION

All elements included in this table should be reported where known for each material tested. The mandatory elements represent the minimum that should be reported for each material type. Where other deliberate additions are made for alloying purpose(s), these are also regarded as mandatory (see Note 1).

Material Type (Table 1.1)	**Mandatory**	**Recommended(2)**	**Optional**
Carbon	C, Si, Mn	P, S	Al(3), N(3), Cr, Mo, Ni, V, As, B, Sb, Sn, Ti, Cu
Carbon Manganese	C, Si, Mn	P, S	Al(3), N(3), Cr, Mo, Ni, V, As, B, Sb, Sn, Ti, Cu
Microalloyed	C, Si, Mn, Nb(1), Ti(1), V(1), Al(1)	P, S	N(3), Cr, Mo, Ni, As, B, Sb, Sn, Cu
Low Alloy Ferritic	C, Si, Mn, Cr(1), Mo(1), V(1)	P, S, Ni	Al(3), N(3), As, B, Cu, Sb, Sn, Ti
High Alloy Ferritic	C, Si, Mn, Cr, Mo(1), V(1), Nb(1), W(1)	P, S, Ni	Al, N, As, B, Cu, Sb, Sn, Ti
Austenitic Stainless	C, Si, Mn, Cr, Ni, Mo(1), Nb(1), Ti(1), B(1), N(1)	P, S	As, Cu, Sb, Sn, V, REM(4)
Ferritic Stainless	C, Si, Mn, Cr, Mo(1), Ni(1), Al(1)	P, S, N	As, B, Cu, Sb, Sn, V, Ti
Duplex Stainless	C, Si, Mn, Cr, Mo, Ni, Cu(1), N(1)	P, S	
Nickel Base, e.g. Nimonic 80A	C, Si, Mn, Fe, Cr, Al, Ti, Co(1), B(1), Ta(1), W(1), Y(1)	P, S	N, As, Sn, Pb, Mg

(1) Elements are mandatory if it is an alloying element and/or included in formal specification for actual or related steel type, e.g. 12% Cr MoV – otherwise such elements are in recommended category.

(2) The elements included as recommended shall be mandatory for all new material test programmes started since 1.1.95.

(3) The information provided shall make it clear whether % given refers to total, soluble and/or insoluble fractions.

(4) REM = rare earth metals.

TABLE 1.6.1

HEAT TREATMENT DETAILS

Heat Treatment Stage	Temp °C	Time(1) h	Cooling Rate* °C/min or Code (see 4.3 on p4.1)	Cooling Medium
1 2 3				
↓				
n				

* Special note shall be made if isothermal treatment(s) used

(1) Time(s) for each heat treatment stage is not a mandatory requirement, but should be stated in the heatr treatment record when know.