TECHNICAL REPORT 4956

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INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Wrought steels for use at elevated temperatures in engines

Aciers corroyés pour usage à températures élevées dans les moteurs

At its meeting in December 1967, ISO/TC 17/SC 4, *Heat-treatable and alloy steels*, agreed to deal with the standardization of creep-resisting steels. ISO/TC 17/SC 4 has studied this item since 1969. In the course of time, five draft proposals were discussed and as a result of this it became obvious that in this field to a considerable extent proprietory specifications of more or less national importance are still applied that a rationalization or harmonization of these specifications is still premature, and that even for types used in several countries the specifications in the various countries differ considerably especially with respect to elevated temperature data.

Under these circumstances, it seemed reasonable to forego publication of an International Standard. However, the agreements achieved during the various negotiations will be made available to everybody interested in this field, in the form of a Technical Report.

To facilitate subsequent publication of an International Standard, data for the amendment of this Technical Report should be sent to the ISO Central Secretariat.

1 Scope

1.1 This Technical Report covers technical delivery requirements and technical information for wrought steels supplied for parts such as bolts, blades, discs or casings in stationary or non-stationary turbines required to withstand relatively high mechanical stresses at elevated temperatures (above about 400 °C) and additionally corrosive attack by hot gases.

NOTE — Other steel types exist which are used mainly for large engine parts; these steel types are not covered by this Technical Report, since they are sold mainly to proprietor specifications only.

1.2 Unless otherwise stated, this Technical Report is applicable to blooms, billets, bars, forgings, strip, sheet, plates and wire in the delivery conditions given in 4.2.

1.3 International Standards exist for heat-resisting steels (see ISO 4955)[1], valve steels for internal combustion engines (see ISO 683/15), and steels for use on and with pressure vessels and boilers (see ISO 2604/1 to 6).

1) At present at the stage of draft.

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Descriptors : steels, rolled products, delivery condition, tests, chemical composition, mechanical properties, heat treatment, turbines.

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2 References

ISO/R 79, *Brinell hardness test for steel.*

ISO/R 81, *Vickers hardness test for steel (load* 5 *to* 100 kgf*).*

ISO 82, *Steel-Tensile testing.*

ISO 86, *Steel-Tensile testing of sheet and strip less than* 3 mm *and not less than* 0,5 mm *thick.*

ISO 89, *Steel-Tensile testing of wire.*

ISO 148, *Steel-Charpy impact test (V-notch).* [1)]

ISO/R 377, *Selection and preparation of samples and test pieces for wrought steel.*

ISO 404, *Steel and steel products — General technical delivery requirements.*

ISO/R 783, *Mechanical testing of steel at elevated temperatures — Determination of lower yield stress and proof stress and proving test.*

3 Ordering

3.1 The purchaser shall state in his enquiry and order

a) the steel type (see table 2);

b) the product form and the dimensions and tolerances of the product (see 4.8);

c) the treatment condition including surface condition (see 4.2);

d) the quantity to be delivered;

e) the requirement class (see table 1);

f) the required type of document (see 5.6).

3.2 Certain options in ordering are permitted by this Technical Report and the purchaser may also state in his equiry and order his related requirements as shown below.

a) whether a product analysis is required (see 4.4.2);

b) whether the mechanical properties for other dimensions than according to table 4 are to be specified;

c) in cases in which tensile and impact properties are to be verified on reference test pieces and in cases in which more than one heat treatment is indicated in tables 4 and 5 for the type of steel concerned, the heat treatment to be applied (see 5.3.3.3);

d) in cases in which minimum proof stress at elevated temperatures is to be verified, the testing temperature selected from table 6 (see 5.4.5);

e) the machining allowances (see 4.7.2).

3.3 The relevant clause of ISO 404 is valid.

4 Requirements

4.1 Manufacture of the steel and of the product

Unless otherwise agreed in the order, the processes used in making the steel and the product are at the manufacturer's discretion. When he so requests, the user shall be informed what steelmaking process is being used.

1) At present at the stage of draft. (Revision of ISO/R 148-1960.)

4.2 Treatment condition at the time of delivery

4.2.1 The surface and heat-treatment condition at the time of delivery is to be agreed at the time of enquiry and order.

4.2.2 Products which are not determined for further hot- or cold-forming operations are usually delivered in the heat-treatment conditions indicated in table 5.

Products intended for further forming operations are usually delivered in the following conditions:

a) in the case of martensitic steels: "annealed on a hardness ≤ 270 HB";

b) in the case of austenitic steels: "treated for further forming operations".

4.2.3 The steels are delivered by casts.

4.3 Requirement classes [1)]

The steels covered by this Technical Report shall be ordered and delivered in accordance with one of the requirement classes given in table 1.

4.4 Chemical composition

4.4.1 The chemical composition of the steels, as given by the cast analysis, shall be in accordance with the specifications in table 2. The cast analysis, if called for in the order, shall be provided by the manufacturer.

4.4.2 The permissible deviations between the values specified in table 2 and the product analysis are given in table 3. If a product analysis is required by the purchaser, this shall be stated in the enquiry and order.

4.5 Mechanical properties

4.5.1 When ordering according to the requirement class 1a, 9 or 10 and according to a heat-treatment condition given in table 5, the hardness values specified in table 4 apply for the product in the delivery condition.

4.5.2 When ordering according to the requirement class 5 or 6 and according to a heat-treatment condition given in table 5, the tensile and impact properties specified in table 4 apply for the product in the delivery condition.

4.5.3 When ordering according to requirement class 7, 8, 9 or 10, the tensile and impact properties specified in table 4 apply for reference test pieces which were prepared in accordance with 5.3.3.3.

4.5.4 When ordering steels according to requirement class 6, 8 or 10, the elevated temperature yield or proof stress values specified in table 6 apply either for a test piece in the delivery condition (requirement class 6) or for a reference test piece (requirement class 8 or 10) (see 5.3.3.4).

4.6 Further material characteristics

There are some further material characteristics for which however it is impossible at the time being to formulate clear requirements. As far as appropriate and possible, annex A gives technical informations for these characteristics.

4.7 Surface quality

4.7.1 All products shall have a workmanlike finish and shall be clean and free from surface imperfections likely to have an adverse effect.

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1) In former International Standards prepared by TC 17/SC 4, the term "type of condition of delivery" was used instead of "requirement class". It was replaced in order to avoid confusion with the term "delivery condition", which is often used for the treatment condition of the steel at the time of delivery.

4.7.2 Hot-rolled, forged, cold-drawn or rough-machined products shall be delivered with a machining allowance for the removal, by machining or grinding of

a) surface decarburization, and

b) surface imperfections.

As long as no International Standard for the machining allowances of creep-resisting steels is available, the allowances shall be agreed at the time of enquiry and order.

4.8 Dimensions and tolerances

4.8.1 The products shall, if possible, be ordered and delivered in accordance with existing International Standards for dimensions and tolerances (see list in annex B). The ordered dimensions must, where applicable, include the minimum machining allowances (see 4.7.2) and the undersize tolerance.

4.8.2 If corresponding International Standards for dimensions and tolerances are not yet available or if the tolerances given in the corresponding International Standard are not applicable for creep-resisting steels, then the dimensions and tolerances shall be agreed at the time of enquiry and order.

5 Testing

5.1 General

5.1.1 For all requirement classes, acceptance tests can be agreed.

5.1.2 If acceptance tests have been agreed the general conditions of ISO 404 regarding

— the place of acceptance,

— the submission for inspection,

— the rights of the inspector,

— the acceptance,

and, furthermore, the conditions given in 5.2 to 5.6 (as far as these are applicable according to the ordered requirement class) are to be observed.

5.2 Test unit and number of sample products and tests

5.2.1 Chemical composition

The cast analysis, if called for in the order, shall be provided by the manufacturer. If a product analysis is required by the purchaser, and if not otherwise agreed at the time of enquiry and order, one sample product shall be taken from each cast.

5.2.2 Mechanical properties

If, according to the ordered requirement class (see table 1) and the required type of document (see 5.6 and 5.1.2) the mechanical properties are to be verified, then the indications in table 7 apply for the test unit and the number of sample products and tests.

5.3 Selection and preparation of samples and test pieces

5.3.1 General

The general conditions given in ISO/R 377 for the selection and the preparation of samples and test pieces shall apply.

5.3.2 Product analysis

For product analysis, the selection and preparation of samples shall be carried out in conformity with the requirements of ISO/R 377.

5.3.3 Mechanical properties

5.3.3.1 For the hardness test, the surface of the sample product or of a test piece taken from the sample product in the delivery condition shall be prepared in accordance with the requirements in ISO/R 79 (Brinell hardness) or ISO/R 81 (Vickers hardness).

5.3.3.2 If the tensile and impact properties at room temperature are to be verified on test pieces in the delivery condition (requirement classes 5 and 6), the samples and test pieces shall be taken from the delivery in accordance with figure 1a or 1b, and shall be prepared in accordance with the International Standards mentioned in figures 1a or 1b.

5.3.3.3 If the tensile and impact properties at room temperature are to be verified on reference test pieces (requirement classes 7, 8, 9 or 10), the test samples shall be taken from the delivery in accordance with figure 1a or 1b and shall be heat treated in accordance with the heat-treatment conditions indicated in table 5 for the relevant steel. If in this table more than one heat treatment is indicated for the steel concerned, the treatment to be applied shall be agreed at the time of enquiry and order.

After the heat-treatment of the samples, the test pieces shall be taken and prepared in accordance with the indications in figure 1a or 1b.

5.3.3.4 If the yield or proof stress at elevated temperatures as specified in table 6 is to be verified on test pieces in the delivery condition (requirement class 6) or on reference test pieces (requirement classes 8 or 10), a test piece according to ISO/R 783 shall be taken under conditions corresponding to those specified for taking the test pieces for the tensile tests at room temperature (see 5.3.3.2 and 5.3.3.3).

5.4 Test methods

5.4.1 Chemical analysis

In cases of dispute, the methods used for the chemical analysis shall be those established by the relevant International Standards. If no International Standards are available, the methods shall be agreed upon at the time of enquiry and order.

5.4.2 The Brinell hardness test shall be made in accordance with ISO/R 79. The Vickers hardness test shall be made in accordance with ISO/R 81.

5.4.3 The tensile test at room temperature shall be made in accordance with the International Standards according to which the test pieces are to be prepared (see figures 1a and b).

5.4.4 The impact test shall be made in accordance with ISO 148 (V-notch). Unless otherwise specified at the time of enquiry and order, the impact value shall be determined by the arithmetic average of three test results.

5.4.5 The yield or proof stress at elevated temperature shall be determined in accordance with ISO/R 783 at a temperature selected from table 6 and agreed at the time of enquiry and order.

5.5 Retests

For retests, ISO 404 is valid.

5.6 Certification of the tests

ISO 404 is valid, acceptable documents being one of the following

- statement of compliance with the order;
- report based on quality control;
- works certificate;
- test certificate;
- certificate of acceptance.

6 Rectification, defects and reclaiming

If not otherwise stated in the foregoing, the conditions given in ISO 404 are valid for

- surface defects;
- rectification;
- internal defects;
- dimensional tolerances;
- reclaiming.

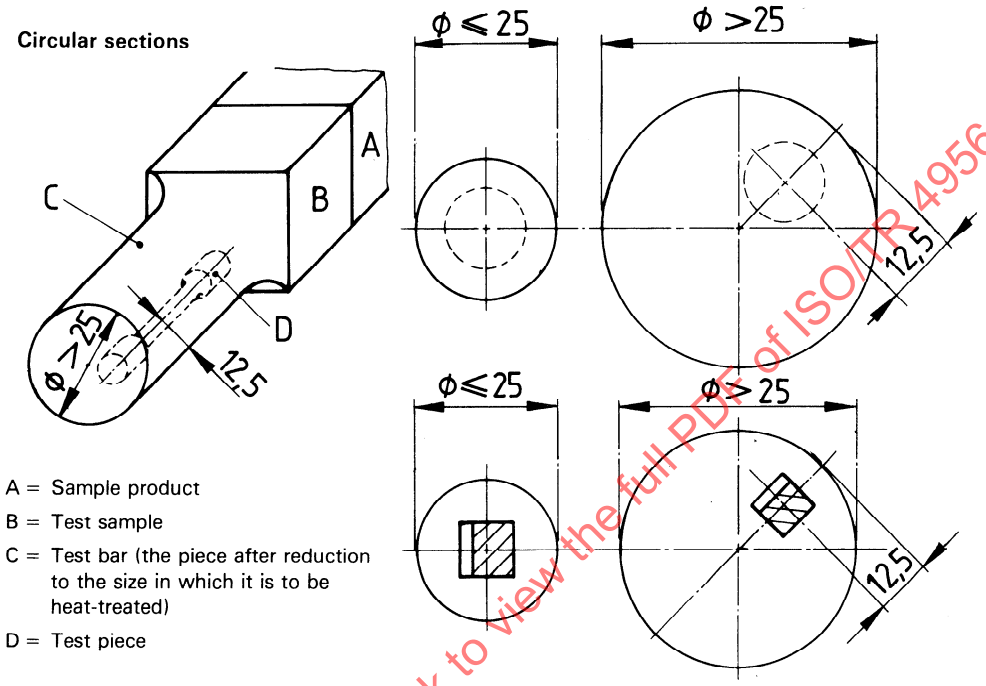
Dimensions in millimetres

Tensile test piece according to ISO 82 with a gauge length $L_o = 5{,}65\sqrt{S_o}$ or according to ISO 89.

ISO-V-notch impact test pieces[1] according to ISO 148.

notch

Circular sections



A = Sample product

B = Test sample

C = Test bar (the piece after reduction to the size in which it is to be heat-treated)

D = Test piece

Rectangular sections

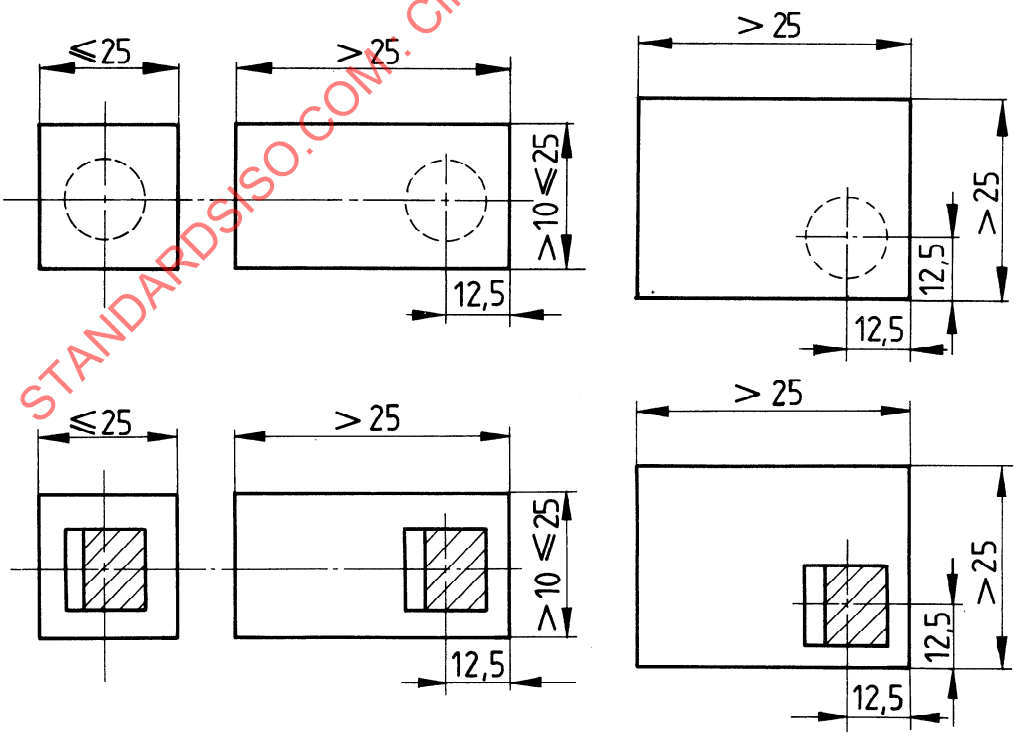


Figure 1a — Location and type of the test pieces for bars and wire with diameters ⩾ 4 mm

1) 3 test pieces in longitudinal or radial direction adjacent to one another.

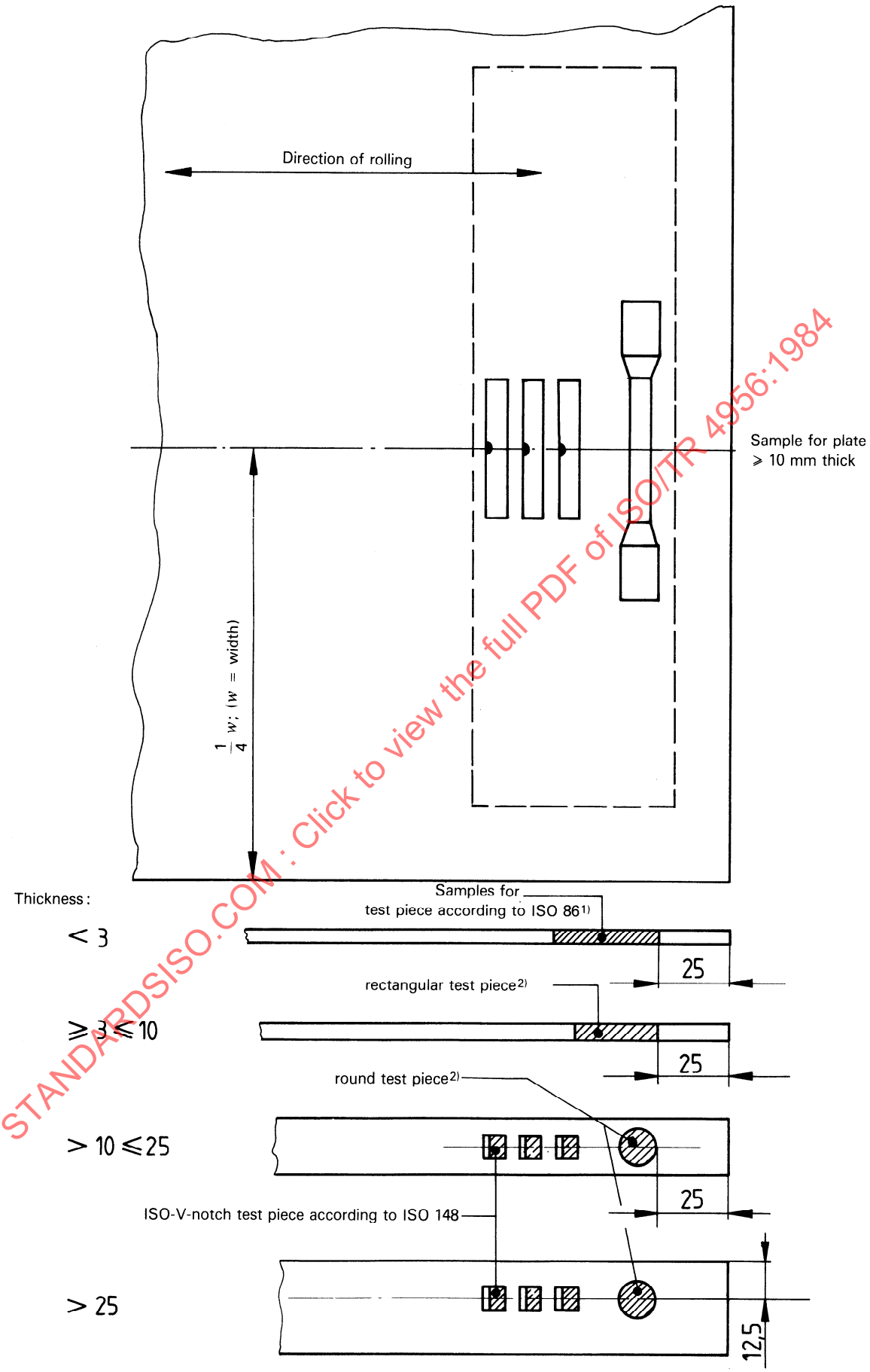


Figure 1b — Location and type of the test piece for sheet, strip or plate

1) ISO 86 recommends test pieces either of 20 mm width and 80 mm gauge length or of 12,5 mm width and 50 mm gauge length.

2) Gauge length in cases of dispute $L_o = 5{,}65\sqrt{S_o}$ (S_o = cross-section).

Table 1 — Requirement classes

1	2	3								4
No.	Requirement	Requirement class*								Required results, see table
		1	1a	5[1)]	6[1)]	7	8	9	10	
1	Chemical composition	x	x	x	x	x	x	x	x	2 and 3
2	Hardness in the delivery condition	—	x	—	—		—	x	x	4
3	Tensile and impact properties									
3a	— at room temperature in the delivery condition	—	—	x	x	—	—	—	—	
3a1										4
3a2	— reference heat treatment condition	—	—	—	—	x	x	x	x	
3b	— at elevated temperatures (proof stress)	—	—	—	x	—	x	—	x	6

*) The numbers of the requirement classes are to be regarded as preliminary until a system for the types of requirement classes has been established.

1) Only applicable in cases where the delivery condition corresponds to a heat-treatment condition specified for the relevant steel in table 5.

Table 2 — Type of steel, specified chemical composition (cast analysis[1]) and product form

Type of steel	Chemical composition, % (*m/m*)											Commonly available product forms[2]		
	C	Si	Mn	P max.	S max.	Cr	Mo	Ni	V	W	Sundry			
	Bainitic and martenesitic steels													
21 CrMoV 5 7	0,17 to 0,25	max. 0,40	0,40 to 0,80	0,030	0,030	1,20 to 1,50	0,65 to 0,80	max. 0,60	0,25 to 0,35	—	—	B		
40 CrMo 5 6	0,35 to 0,45	0,15 to 0,40	0,40 to 0,70	0,035	0,035	1,00 to 1,50	0,50 to 0,80	—	—	—	—	B		
40 CrMoV 4 6	0,36 to 0,44	0,15 to 0,35	0,45 to 0,85	0,030	0,030	0,90 to 1,20	0,55 to 0,75	—	0,25 to 0,35	—	—	B		
X 12 Cr 13	0,09 to 0,15	max. 1,00	max. 1,00	0,040	0,030	11,50 to 14,00	—	max. 1,00	—	—	—	B		P
X 20 CrMoNiNbV 11 1	0,16 to 0,24	0,10 to 0,50	0,30 to 1,00	0,030	0,030	10,00 to 12,00	0,50 to 1,00	0,30 to 1,00	0,10 to 0,30	—	B : max. 0,008 0 N : max. 0,10 Nb : 0,20 to 0,50			
X 12 CrNiMoV 12 3	0,08 to 0,15	max. 0,35	0,50 to 0,90	0,030	0,025	11,00 to 12,50	1,50 to 2,00	2,00 to 3,00	0,25 to 0,40	—	N : 0,020 to 0,040	B	S	P
X 21 CrMoNiV 12 2	0,17 to 0,25	max. 0,50	max. 1,00	0,035	0,030	11,00 to 12,50	0,70 to 1,20	0,30 to 1,00	0,20 to 0,35	—	—	B		
X 12 CrMoV 12 6	0,08 to 0,16	max. 0,60	0,40 to 1,00	0,035	0,035	11,50 to 13,00	0,40 to 0,80	max. 1,00	0,10 to 0,30	—	—	B		
X 12 CrMo 12 6	0,08 to 0,16	max. 0,60	0,40 to 1,00	0,035	0,035	11,50 to 13,00	0,40 to 0,80	max. 1,00	—	—	—	B		
	Austenitic steels													
X 11 CrNiWTi 17 13 3	0,07 to 0,15	max. 1,00	max. 1,00	0,045	0,030	15,50 to 17,50	—	12,00 to 14,50	—	2,50 to 3,50	$4 \times \% C \leqslant Ti \leqslant 0,80$ B : max. 0,006 0			
X 6 NiCrTiMoVB 25 15 2	0,03 to 0,08	max. 1,00	max. 2,00	0,025	0,015	13,50 to 16,00	1,00 to 1,50	24,00 to 27,00	0,10 to 0,50	—	Ti : 1,90 to 2,30 B : 0,003 to 0,010	B	S	P

1) Elements not quoted in this table shall not be intentionally added to the steel without the agreement of the purchaser, other than for the purpose of finishing the heat. All reasonable precautions shall be taken to prevent the addition, free scrap or other materials used in manufacture, of such elements which affect the hardenability, mechanical properties and applicability.

2) B = bars and forging (including wire);
S = sheet and strip 0,5 to < 3 mm thick;
P = plate.

Table 3 — Permissible deviations between specified analysis and product analysis

Type of steel	Permissible deviations[1], % (*m/m*)										
	C	Si	Mn	P	S	Cr	Mo	Ni	V	W	Sundry
21 CrMoV 5 7	± 0,03	+ 0,04	± 0,06	+ 0,004	+ 0,004	± 0,07	± 0,04	+ 0,05	± 0,03	—	—
40 CrMo 5 6	± 0,03	± 0,04	± 0,06	+ 0,005	+ 0,005	± 0,07	± 0,04	—	—	—	—
40 CrMoV 4 6	± 0,03	± 0,04	± 0,06	+ 0,005	+ 0,005	± 0,07	± 0,04	—	± 0,03	—	—
X 12 Cr 13	± 0,01	± 0,05	+ 0,04	+ 0,004	+ 0,003	± 0,15	—	+ 0,05	—	—	—
X 20 CrMoNiNbV 11 1	± 0,02	± 0,04	± 0,04	+ 0,003	+ 0,003	± 0,15	± 0,04	± 0,05	± 0,03	—	B : + 0,001 0 N : + 0,010 Nb : ± 0,05
X 12 CrNiMoV 12 3	± 0,01	+ 0,04	± 0,04	+ 0,003	+ 0,003	± 0,15	± 0,05	± 0,07	± 0,03	—	N : ± 0,010
X 21 CrMoNiV 12 2	± 0,02	+ 0,04	+ 0,04	+ 0,004	+ 0,003	± 0,15	± 0,05	± 0,05	± 0,03	—	—
X 12 CrMoV 12 6	± 0,01	+ 0,05	± 0,04	+ 0,004	+ 0,004	± 0,15	± 0,04	+ 0,05	± 0,03	—	—
X 12 CrMo 12 6	± 0,01	+ 0,05	± 0,04	+ 0,004	+ 0,004	± 0,15	± 0,04	± 0,05	—	—	—
X 11 CrNiWTi 17 13 3	± 0,01	+ 0,05	+ 0,04	+ 0,005	+ 0,004	± 0,20	—	± 0,12	—	± 0,10	Ti : ± 0,05 B : + 0,001 0
X 6 NiCrTiMoVB 25 15 2	± 0,01	+ 0,05	+ 0,05	+ 0,003	+ 0,003	± 0,20	± 0,05	± 0,20	± 0,03	—	Ti : ± 0,08 B : ± 0,001 0

1) The deviations, other than when maxima or minima only are specified, apply either above or below the specified limits of the range but not both above and below for the same element from different sample products from the same cast.

Table 4 — Hardness, tensile and impact properties at room temperature

Type of steel	Heat treatment[1]	Diameter (bars and forgings)[2]	Thickness (flat products)	Hardness[3]	$R_{p0,2}$[4] min.	$R_{p1,0}$[4] min.	R_m[4]	A_5[5] long. min.	KV[6][7] long. min.
		mm	mm	HB	N/mm²	N/mm²	N/mm²	%	J
21 CrMoV 5 7	Q + T	⩽ 250		205 to 250	550	—	700 to 850	16	63
40 CrMo 5 6	Q + T	⩽ 200			635	—	850 to 1 000	14	30
40 CrMoV 4 6	Q + T	⩽ 100			700	—	850 to 1 000	14	30
		> 100 ⩽ 200			635	—	800 to 950	14	25
X 12 Cr 13	A	⩽ 160	0,5 to 25		265	—	470 to 670	20	60
X 12 Cr 13	Q + T	⩽ 160	0,5 to 25	175 to 235	420	—	590 to 780	16	40
X 20 CrMoNiNbV 11 1	Q + T	⩽ 250		265 to 310	750	—	900 to 1 050	10	20
X 12 CrNiMoV 12 3	Q + T	⩽ 150		285 to 331	785	—	930 to 1 130	14	40
X 12 CrNiMoV 12 3	Q + T		0,5 to 6	280 to 330	785	—	930 to 1 130	10	—
X 21 CrMoNiV 12 2	Q + T1	⩽ 250		235 to 280	590	—	780 to 930	14	27
X 21 CrMoNiV 12 2	Q + T2	⩽ 250		265 to 310	700	—	900 to 1 050	11	20
X 12 CrMoV 12 6	Q + T	⩽ 150			585	—	770 to 930	15	25
X 12 CrMo 12 6	Q + T	⩽ 75		⩾ 192	490	—	680 to 880	20	—
X 11 CrNiWTi 17 13 3	hot cold worked	⩽ 60		175 to 235	390	430	600 to 800	25	55
X 11 CrNiWTi 17 13 3	S + P	⩽ 100			220	260	500 to 730	35	70
X 6 NiCrTiMoVB 25 15 2	S + P	5 to 250	0,5 to 63	248 to 341	600	640	900 to 1 100	15	40

1) A = annealed, Q = quenched, T = tempered, S = solution treated, P = precipitation hardened (see also table 5).

2) Including wire.

3) In cases of dispute the tensile strength value is authoritative.

4) $R_{p\,0,2}$ = 0,2 % proof stress

$R_{p\,1,0}$ = 1 % proof stress

R_m = tensile strength.

5) A = Elongation after fracture. In the case of bars, the values are valid for test pieces with a gauge length of $L_o = 5{,}65\sqrt{S_o}$ (S_o = original cross-sectional area). In the case of flat products, the values are valid for both test pieces specified in ISO 86 (ISO 86 recommends test pieces either of 20 mm width and 80 mm gauge length or of 12,5 mm width and 50 mm gauge length).

6) Average of three test results. One individual value may be below the specified value, provided that it is not less than 70 % of that value.

7) KV = impact energy of ISO-V-notch test pieces (see ISO 148).

Table 5 — Heat treatment[1]

Type of steel	Heat treatment symbol[2]	Annealing or quenching or solution treatment temperature °C	Annealing or quenching or solution treatment cooling[3]	Tempering[4] or precipitation treatment temperature (and time) °C
21 CrMoV 5 7	Q + T	920 to 980	a, o	680 to 740 (min. 2 h)
40 CrMo 5 6	Q + T	840 to 870	o	600 to 700
40 CrMoV 4 6	Q + T1*	880 to 950	o	670 to 720
40 CrMoV 4 6	Q + T2*	940 to 970	o	600 to 700
X 12 Cr 13	A	700 to 780	a	
X 12 Cr 13	Q + T	950 to 1 000	a, o	700 to 750 (min. 2 h)
X 20 CrMoNiNbV 11 1	Q + T	1 100 to 1 150	a, o	670 to 750 (min. 2 h)
X 12 CrNiMoV 12 3	Q + T	1 035 to 1 065	o	600 to 700
X 21 CrMoNiV 12 2	Q + T1	1 020 to 1 070	a, o, w	680 to 740 (min. 2 h)
X 21 CrMoNiV 12 2	Q + T2	1 020 to 1 070	a, o, w	640 to 700 (min. 2 h)
X 12 CrMoV 12 6	Q + T	1 050 ± 10	a, o	650 to 700
X 12 CrMo 12 6	Q + T	970 to 1 020	o	650 to 750
X 11 CrNiWTi 17 13 3	hot cold worked[5]			
X 11 CrNiWTi 17 13 3	S + P	1 100 to 1 150	a, w	750 to 800
X 6 NiCrTiMoVB 25 15 2	S + P	980 ± 10	o, w	720 ± 10

*) Q + T1 would apply to sizes up to 100 mm, Q + T2 to sizes above 100 up to 200 mm.

1) Except in cases where test samples are to be reference heat treated, the indications in this table are for guidance only.

2) A = annealed, P = precipitation hardened, Q = quenched, S = solution treated, T = tempered.

3) a = air, o = oil, w = water.

4) If a stress relief treatment is necessary, the stress relief temperature should be at least 30 °C lower than the tempering temperature.

5) Hot cold worked at about 750 °C.

Table 6 — Proof stress at elevated temperatures

Type of steel	Heat treatment[1]	$R_{p0,2}$ min. in N/mm², at T = ... °C												
		20	100	200	300	400	450	500	550	600	650	700	750	800
21 CrMoV 5 7	Q + T	550	530	500	460	410	380	350	—	—	—	—	—	—
40 CrMo 5 6	Q + T	635	630	610	575	525	490	450	—	—	—	—	—	—
40 CrMoV 4 6	Q + T1	700	670	635	598	540	500	460	403	—	—	—	—	—
40 CrMoV 4 6	Q + T2	635	630	615	580	525	480	435	—	—	—	—	—	—
X 12 Cr 13	A	265	255	240	225	205	195	185	175	—	—	—	—	—
X 12 Cr 13	Q + T	420	410	380	345	305	285	—	—	—	—	—	—	—
X 20 CrMoNiNbV 11 1	Q + T	750	730	700	655	580	530	470	400	315	—	—	—	—
X 12 CrNiMoV 12 3	Q + T	740	680	655	650	610	560	505	400	250				
X 21 CrMoNiV 12 2	Q + T1	590	560	530	480	420	380	335	280	205	—	—	—	—
X 21 CrMoNiV 12 2	Q + T2	690	650	600	550	485	440	390	330	250	—	—	—	—
X 12 CrMoV 12 6	Q + T	615	575	555	535	510	480	450	—	—	—	—	—	—
X 12 CrMo 12 6	Q + T	490	480	450	410	380	360	330	—	—	—	—	—	—
X 11 CrNiWTi 17 13 3	hot cold worked	390	383	373	324	275	250	226	197	167	—	—	—	—
X 11 CrNiWTi 17 13 3	S + P	220	210	195	176	157	155	152	143	137	—	—	—	—
X 6 NiCrTiMoVB 25 15 2	S + P	600	590	570	555	535	520	510	490	465	425	375	305	225

1) A = annealed, Q = quenched, T = tempered, S = solution treated, P = precipitation hardened (see also table 5).

Table 7 — Test units, number of sample products and tests

No.	Requirement	Test unit[1]	Number of	
			sample products per test unit	tests per sample product
1	Chemical composition	C	see 5.2.1	
2	Hardness in the delivery condition	C + D[2] + T	to be agreed	
3 3a 3a1	Tensile and impact properties — at room temperature in the delivery condition	C + D[2] + T	1	1 tensile test and 3 impact tests[3]
3a2	— reference heat treatment condition	C + D[2]		
3b	— at elevated temperatures (proof stress)	C + D[2] + T[4]	1	1

1) The tests are to be carried out separately for each cast (symbol C) or for each cast and each dimension (symbol C + D) or for each cast, each dimension and each heat-treatment batch (symbol C + D + T).

2) If the consignment consists of products of the same type with thickness which differ by not more than 3:1 and which were manufactured by the same forming process (hot formed or cold formed), then the products can be conjoint into one test unit.

3) If specified in table 4 for the steel type and heat treatment condition concerned.

4) Where the elevated temperature properties are to be verified on reference test bars (see 5.3.3.4), the tests are not to be carried out separately for each heat-treatment batch.

Annex A

Technical information on wrought steels for use at elevated temperatures in engines

A.1 Introduction

Clause 4 of this Technical Report covers those requirements which can be clearly defined and which seem necessary to specify a steel of fairly uniform properties. In the following, these requirements are supplemented by indications on some further important properties which for one reason or another, for example because of difficulties in their verification or because they are based on a too limited number of tests, cannot, at present, be formulated as requirements but should be regarded as technical information.

A.2 Creep resistance

The steels given in table 2 have, by virtue of their alloy content, an increased resistance to creep.

In table 8, the average creep stresses for 1 % elongation ($R_{p1,0}$) and rupture (R_m) after duration of 10 000 and 100 000 h are given for guidance only.

A.3 Physical properties

In table 9, some physical properties of the steels are given for guidance. In table 10, the static and dynamic moduli of elasticity are given for guidance.

A.4 Technological properties

A.4.1 The steels are suitable for hot working. The optimum hot-working conditions shall, where necessary, be requested from the manufacturer.

A.4.2 The steels are suitable for cold forming. However, the marked tendency of austenitic steels to work-harden should be noted.

A.4.3 The steels may generally be welded by the usual welding processes. It is, however, recommended that users who have not had experience in welding these steels should consult the suppliers regarding appropriate welding conditions.