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Welding — Determination of Ferrite Number (FN) in austenitic and duplex ferritic-austenitic Cr-Ni stainless steel weld metals

Soudage — Détermination de l'indice de ferrite (FN) dans le métal fondu en acier inoxydable austénitique et duplex ferritique-austénitique au chrome-nickel

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by IIW, the International Institute of Welding, Commission II.

Any feedback, question or request for official interpretation related to any aspect of this document should be directed to IIW via your national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This third edition cancels and replaces the second edition (ISO 8249:2000), which has been technically revised. The main changes compared to the previous edition are as follows:

— corrections have been made to Table 2 (previously Table 1);

— minor editorial changes in Clause 9 (previously Clause 8) and throughout the document have been made.

Introduction

At present, there is no universal opinion concerning the best experimental method that gives an absolute measurement of the amount of ferrite in a weld metal, either destructively or non-destructively. This situation has led to the development and use, internationally, of the concept of a "Ferrite Number" or FN. A Ferrite Number is a description of the ferrite content of a weld metal determined using a standardized procedure. Such procedures are laid down in this document. The Ferrite Number of a weld metal has been considered approximately equivalent to the percentage ferrite content, particularly at low FN values. More recent information suggests that the FN can overstate the volume percent ferrite at higher FN by a factor in the order of 1,3 to 1,5, which depends to a certain extent on the actual composition of the alloy in question.

Although other methods are available for determining the Ferrite Number, the standardized measuring procedure, laid down in this document, is based on assessing the tear-off force needed to pull the weld metal sample from a magnet of defined strength and size. The relationship between tear-off force and FN is obtained using primary standards consisting of a non-magnetic coating of specified thickness on a magnetic base. Each non-magnetic coating thickness is assigned an FN value.

The ferrite content determined by this method is arbitrary and is not necessarily the true or absolute ferrite content. In recognition of this fact, the term "Ferrite Number" (FN) is used instead of "ferrite per cent" when quoting a ferrite content determined by this method. To help convey the message that this standardized calibration procedure has been used, the terms "Ferrite Number" and "FN" are capitalized as proper nouns.

Welding — Determination of Ferrite Number (FN) in austenitic and duplex ferritic-austenitic Cr-Ni stainless steel weld metals

1 Scope

This document specifies the method and apparatus for:

— the measurement of the delta ferrite content, expressed as Ferrite Number (FN), in largely austenitic and duplex ferritic-austenitic stainless steel[1)] weld metal through the attractive force between a weld metal sample and a standard permanent magnet;

— the preparation and measurement of standard pads for manual metal arc covered electrodes. The general method is also recommended for the ferrite measurement of production welds and for weld metal from other processes, such as gas tungsten arc welding, gas shielded metal arc welding and submerged arc welding (in these cases, the way of producing the pad should be defined);

— the calibration of other instruments to measure FN.

The method laid down in this document is intended for use on weld metals in the as-welded state and on weld metals after thermal treatments causing complete or partial transformation of ferrite to any non-magnetic phase. Austenitizing thermal treatments which alter the size and shape of the ferrite change the magnetic response of the ferrite.

The method is not intended for measurement of the ferrite content of cast, forged or wrought austenitic or duplex ferritic-austenitic steel samples.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Principle

The measurement of the ferrite content of largely austenitic stainless steel weld metal through the attractive force between a weld metal sample and a permanent magnet is based on the fact that the attractive force between a two-phase (or multiphase) sample containing one ferromagnetic phase and one (or more) non-ferromagnetic phase(s) increases as the content of the ferromagnetic phase increases. In largely austenitic and duplex ferritic-austenitic stainless steel weld metal, ferrite is magnetic, whereas austenite, carbides, sigma phase and inclusions are non-ferromagnetic.

1) The term "austenitic-ferritic (duplex) stainless steel" is sometimes applied in place of "duplex ferritic-austenitic stainless steel".

5 Calibration

5.1 Coating thickness standards

The coating thickness standards shall consist of non-magnetic copper applied to an unalloyed steel base of size 30 mm × 30 mm. The thickness of the unalloyed steel base shall be equal to or greater than the experimentally determined minimum thickness at which a further increase of the thickness does not cause an increase of the attractive force between the standard permanent magnet and the coating thickness standard. The thickness of the non-magnetic copper coating shall be known to an accuracy of ±5 % or better. The chemical composition of unalloyed steel shall be within the limits given in Table 1.

Table 1 — Chemical composition limits – unalloyed steel

Element	Limit % (by mass)
C	0,08 to 0,13
Si	0,10 maximum
Mn	0,30 to 0,60
P	0,040 maximum
S	0,050 maximum

The copper coating may be covered by a chromium flash. The force required to tear off a given permanent magnet from the copper coating side of such a standard increases as the thickness of the copper coating decreases.

To ensure adequate reproducibility of the calibration, the coating thickness standards defined above should be used. In particular, coating thickness standards produced by the US National Institute of Standards and Technology (NIST, formerly National Bureau of Standards or NBS) may be used.

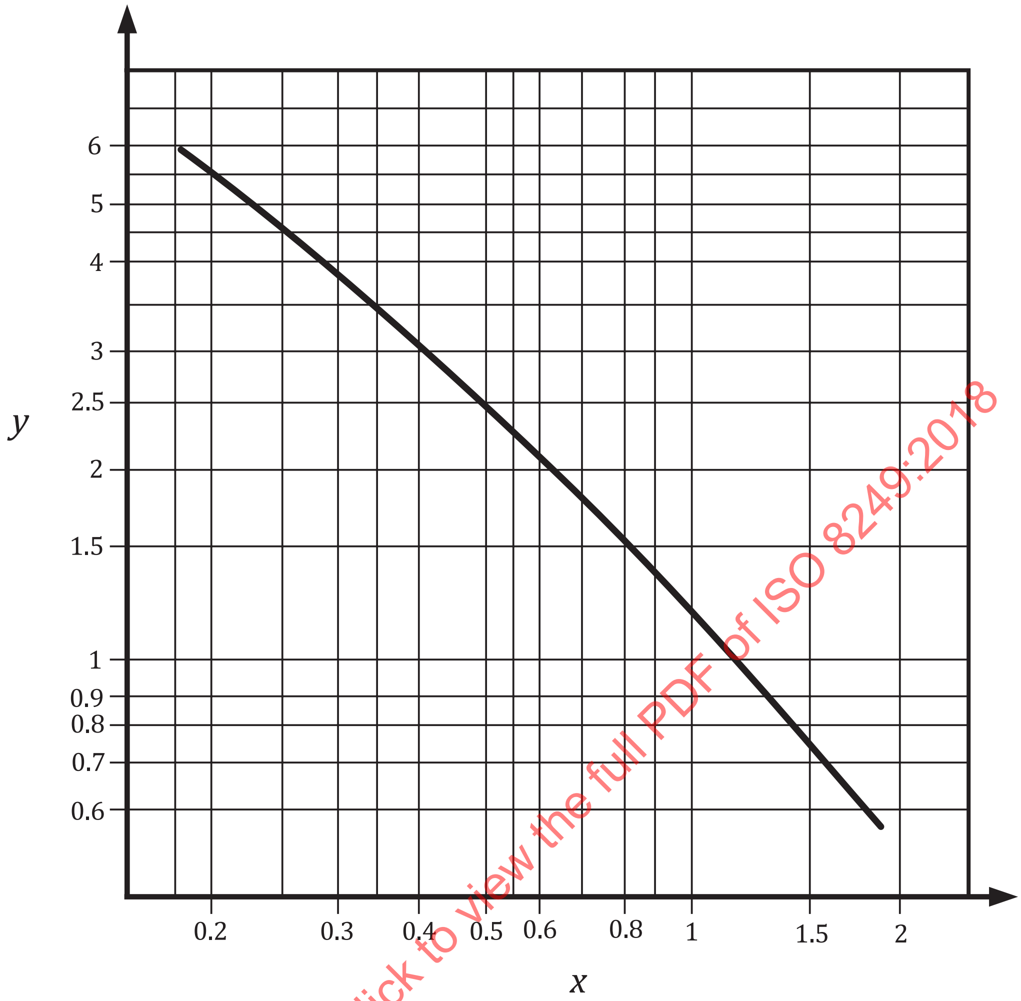
5.2 Magnet

The standard magnet shall be a permanent magnet of cylindrical shape, 2 mm in diameter and about 50 mm in length. One end of the magnet shall be hemispherical, with a 1 mm radius and polished. As an example, such a magnet can be made of 36 % cobalt magnet steel, 48,45 mm ± 0,05 mm long, magnetically saturated and then diluted to 85 %. The magnetic strength of the magnet shall be such that the force needed to tear off the standard magnet from the different coating thickness standards is within ±10 % of the relationship shown in Figure 1 (the weight of the magnet excluded). This is equivalent to a relationship between tear-off force and Ferrite Number of 5,0 FN/g ± 0,5 FN/g.

5.3 Instruments

The measurement by this method shall be made by an instrument enabling an increasing tear-off force to be applied to the magnet perpendicularly to the surface of the test specimen. The tear-off force shall be increased until the permanent magnet is detached from the test specimen. The instrument shall accurately measure the tear-off force which is required for detachment. The reading of the instrument may be directly in FN or in grams-force or in other units. If the reading of the instrument is in units other than FN, the relationship between the FN and the instrument reading shall be defined by a calibration curve.

NOTE Many instruments used to measure the thickness of a non-magnetic coating over a ferromagnetic base are suitable (e.g. MAGNE-GAGE of USA origin) and some commercially available instruments are designed directly for measurement of ferrite content (e.g. ALPHA-PHASE-METER of former USSR origin). In addition, after suitable in-house alterations, some laboratory balances can be used.



Key

x non-magnetic coating thickness, millimetres (mm)

y tear-off force, gram force (gf)

Figure 1 — Relationship between the tear-off forces of the standard magnet defined in 5.2 and the coating thickness standards defined in 5.1

5.4 Calibration curve

In order to generate a calibration curve, determine the force needed to tear off the standard magnet defined in 5.2 from several coating thickness standards defined in 5.1. Then, convert the thickness of non-magnetic coating of the coating thickness standards into FN in accordance with Table 2, or in accordance with Formula (1)[4]:

$$FN = \exp\{1{,}805\,9 - 1{,}118\,86\,[\ln(t)] - 0{,}177\,40\,[\ln(t)]^2 - 0{,}035\,02\,[\ln(t)]^3 - 0{,}003\,67\,[\ln(t)]^4\} \quad (1)$$

where t is the non-magnetic coating thickness, expressed in millimetres.

Finally, plot the calibration curve as the relationship between the tear-off force in the units of the instrument reading and the corresponding FN.

To calibrate the instrument for measurement of ferrite content within the range from 0 FN to approximately 30 FN, which is appropriate for nominally austenitic stainless steel weld metals, a set consisting of a minimum of eight standards with copper coating thicknesses between approximately 0,17 mm and approximately 2 mm is recommended.

NOTE This calibration procedure can give misleading results if used on instruments measuring the ferrite content in ways other than through the attractive force or on instruments measuring ferrite through the attractive force but employing other than the standard magnet defined in 5.2. Instruments which cannot be calibrated by the coating thickness standards and by the procedure specified in 5.2 to 5.4 can be calibrated as described in Clause 8.

To extend the calibration from approximately 30 FN to 100 FN, which is appropriate for duplex ferritic-austenitic stainless steel weld metals, a set consisting of a minimum of five standards with coating thicknesses between 0,03 mm and 0,17 mm is recommended.

Table 2 — Relationship between Ferrite Number and thickness of non-magnetic coating of coating thickness standards (specified in 5.1) for calibration of instruments for measurement of ferrite content through attractive force (specified in 5.3) using the standard magnet (specified in 5.2)

Coating thickness *t* mm	FN	Coating thickness *t* mm	FN	Coating thickness *t* mm	FN	Coating thickness *t* mm	FN	Coating thickness *t* mm	FN
0,020	110,5	0,049	68,3	0,078	51,0	0,134	35,3	0,300	19,1
0,021	108,0	0,050	67,5	0,079	50,6	0,136	34,9	0,320	18,1
0,022	105,7	0,051	66,7	0,080	50,2	0,138	34,5	0,340	17,2
0,023	103,4	0,052	65,9	0,082	49,3	0,140	34,2	0,360	16,4
0,024	101,3	0,053	65,1	0,084	48,6	0,142	33,8	0,380	15,7
0,025	99,2	0,054	64,4	0,086	47,8	0,144	33,5	0,400	15.0
0,026	97,3	0,055	63,7	0,088	47,1	0,146	33,2	0,420	14,4
0,027	95,4	0,056	63,0	0,090	46,4	0,148	32,8	0,440	13,8
0,028	93,6	0,057	62,3	0,092	45,7	0,150	32,5	0,460	13,2
0,029	91,9	0,058	61,6	0,094	45,1	0,155	31,7	0,480	12,7
0,030	90,3	0,059	60,9	0,096	44,4	0,160	31,0	0,500	12,3
0,031	88,7	0,060	60,3	0,098	43,8	0,165	30,3	0,550	11,2
0,032	87,2	0,061	59,7	0,100	43,2	0,170	29,7	0,600	10,3
0,033	85,8	0,062	59,1	0,102	42,6	0,175	29,0	0,650	9,6
0,034	84,4	0,063	58,5	0,104	42,1	0,180	28,4	0,700	8,9
0,035	83,0	0,064	57,9	0,106	41,5	0,185	27,9	0,750	8,3
0,036	81,7	0,065	57,3	0,108	41,0	0,190	27,3	0,800	7,7
0,037	80,5	0,066	56,8	0,110	40,5	0,195	26,8	0,900	6,8
0,038	79,3	0,067	56,2	0,112	40,0	0,200	26,3	1,000	6,1
0,039	78,1	0,068	55,7	0,114	39,5	0,205	25,8	1,200	4,93
0,040	77,0	0,069	55,2	0,116	39,0	0,210	25,3	1,400	4,09
0,041	75,9	0,070	54,7	0,118	38,6	0,220	24,4	1,600	3,45
0,042	74,8	0,071	54,2	0,120	38,1	0,230	23,6	1,800	2,94
0,043	73,8	0,072	53,7	0,122	37,7	0,240	22,8	2,000	2,54
0,044	72,8	0,073	53,2	0,124	37,2	0,250	22,1	2,200	2,21
0,045	71,8	0,074	52,8	0,126	36,8	0,260	21,4	2,400	1,94

Table 2 *(continued)*

Coating thickness *t* mm	FN	Coating thickness *t* mm	FN	Coating thickness *t* mm	FN	Coating thickness *t* mm	FN	Coating thickness *t* mm	FN
0,046	70,9	0,075	52,3	0,128	36,4	0,270	20,8	2,600	1,72
0,047	70,0	0,076	51,9	0,130	36,0	0,280	20,2	2,800	1,53
0,048	69,1	0,077	51,4	0,132	35,6	0,290	19,6	3,000	1,36

6 Standard method for covered electrode test pads

6.1 Dimensions of weld metal test specimens

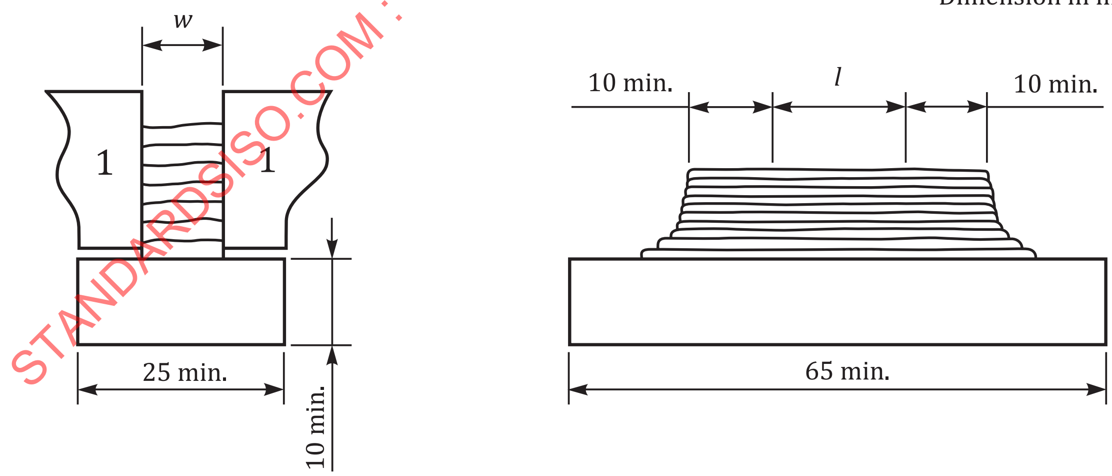
Standard weld metal test specimens for manual electrodes shall be of the size and shape indicated in Figure 2. For the measurement of ferrite content by instruments/magnets or processes other than those specified in 5.2 and 5.3, a larger specimen can be necessary. In such cases, the size and way of producing the pad shall be clearly and carefully defined.

6.2 Depositing weld metal test specimens

a) The weld pad shall be built up between two copper bars laid parallel on the base plate. Spacing shall be adjusted to accommodate the electrode size to be used as specified in Table 3.

b) The weld pad shall be built up by depositing layers one on top of the other to a minimum height of 12,5 mm (see the Note on Figure 2). Each layer shall be made in a single pass for electrode diameters ≥4 mm. For small diameters, each layer except the top layer shall be constituted by two or more beads deposited with a maximum weave of 3 times the core wire diameter. The arc shall not be allowed to come into contact with the copper bar.

Dimension in millimetres



Key

1 copper bar of dimensions 70 × 25 × 25

l length of the area where ferrite content is measured (see Table 3)

w width of the area where ferrite content is measured (see Table 3)

NOTE The base metal is preferably austenitic Cr-Ni steel type X2CrNi18-9 or X5CrNi18-9 (see ISO 15510) and, in this case, the minimum pad height is 13 mm. Mild steel (C-Mn steel) can also be used and, in this case, the minimum pad height is 18 mm.

Figure 2 — Weld metal specimen for ferrite determination

c) The arc length shall be as short as practicable.

d) The welding currents shall comply with the values given in Table 3. The weld stops and starts shall be located at the ends of the weld build-up. The welding direction shall be changed after each pass.

e) The weld pad may be cooled between passes by water quenching no sooner than 20 s after the completion of each pass. The maximum temperature between passes shall be 100 °C. Each pass of the last layer shall be air cooled to a temperature below 425 °C before water quenching.

f) Each weld pass shall be cleaned before the next is deposited.

g) In all cases, the topmost layer, at least, shall consist of a single bead deposited with a maximum weave of 3 times the core wire diameter.

Table 3 — Welding parameters and deposit dimensions

Electrode diameter	Welding current[a]	Approximate dimensions	
		Width, *w*	Length, *l*
mm	A	mm	mm
1,6	35 to 45	12,5	30
2	45 to 55	12,5	30
2,5	65 to 75	12,5	40
3,2	90 to 100	12,5	40
4	120 to 140	12,5	40
5	165 to 185	15	40
6,3	240 to 250	18	40

[a] Or 90 % of the maximum value recommended by the electrode manufacturer.

6.3 Measuring

6.3.1 Surface finishing

After welding, the weld build-up of nominally austenitic stainless steel weld metals (<30 FN) shall be prepared smooth and flat, taking care to avoid heavy cold working[2)] of the surface; this aim can be achieved by draw filing with a sharp clean 350 mm flat mill bastard file held on both sides of the weld and with the long axis of the file perpendicular to the long axis of the weld. Draw filing shall be accomplished by smooth forward strokes along the length of the weld with a firm downward pressure being applied. The weld shall not be cross-filed.

After welding, the weld build-up of duplex ferritic-austenitic stainless steel weld metals (>30 FN) shall be ground with successively finer abrasives to a finish of 600 grit or finer. Care shall be taken during grinding to avoid excessive pressure that leads to burnishing or overheating of the surface.

The finished surface shall be smooth with all traces of weld ripple removed. The prepared surface shall be continuous over the length to be measured and not less than 5 mm in width.

6.3.2 Individual measurements

A minimum of six ferrite readings shall be taken at different locations on the finished surface along the longitudinal axis of the weld bead. Care shall be taken to isolate the weldment under test from vibrations which can cause premature magnet detachment during measuring.

For weld metals of 20 FN or less, only a single reading need be taken at each location. For weld metals above 20 FN, five readings shall be taken at any single location, and only the reading corresponding to

2) Cold working can produce martensite, which is also ferromagnetic and gives a false ferrite indication.

the highest FN amongst those five readings shall be accepted as the FN for that location. A minimum of six locations shall be so measured as to obtain the required values for averaging.

6.3.3 Reporting

The six or more accepted readings obtained shall be averaged to a single value for conversion to the Ferrite Number reported for the weld metal under test.

7 Standard methods for test pads of other processes and for production welds

7.1 Standard method for test pads for other weld metals

The standard method for producing covered electrode test pads may be almost directly applicable to other weld metals, e.g., flux cored arc weld deposits. In preparing such test pads, it can be necessary to increase the pad length so that the area of ferrite measurements does not include the weld crater. For submerged arc weld metal, it can be necessary to increase both the test pad width and length. For all test pads, the pad shall consist of a minimum of six layers, with at least the top layer consisting of a single bead. In general, preparation and measurement shall follow the instructions of Clause 6 as far as possible.

7.2 Production welds

The method of depositing the weld test specimen has a considerable influence on the result of ferrite content measurement. Consequently, the results of ferrite content measurement obtained on specimens deposited in a way differing from that specified in 6.1 and 6.2, or 7.1, and on production welds are likely to differ from the results obtained on specimens deposited in accordance with 6.1 and 6.2, or 7.1. In all cases, however, ferrite content measurement shall be made along the approximate centreline of a given weld bead.

It is necessary to ensure that the measurement is not disturbed by the incidental presence of strongly ferromagnetic materials, such as mild steel or cast iron. During measurement, such materials shall be kept at a distance of at least 18 mm from permanent magnets of the size and strength of the standard magnet. Other magnets and/or instruments can require larger or smaller distances to be free from the effect of nearby strongly ferromagnetic materials.

Caution is necessary when measuring the ferrite in cladding deposited on ferromagnetic materials, and when measuring the ferrite in thin stainless steel welds (e.g. less than 5 mm thick). The first case can lead to false high values, and the second can lead to false low values. The required minimum stainless steel weld thickness for correct ferrite measurement depends upon the depth of material sensed by the particular instrument in use.

8 Other methods

8.1 Methods

Methods for determining ferrite content other than through the evaluation of attractive force or methods differing from that laid down in this document may be used, such as volumetric determination by magnetic saturation, provided that they have been calibrated by secondary standards in which the ferrite content has been determined by the method laid down in this document. Secondary standards can be prepared using the method specified in 6.1 and 6.2, by assigning to them FN values by the method specified in 6.3.

NOTE Secondary IIW standards, prepared in accordance with Annex A were previously produced by TWI (The Welding Institute) in the United Kingdom. Secondary IIW standards, prepared in accordance with Annex B, are available from the National Institute of Standards and Technology (NIST), Office of Reference Materials in the USA (https://www.nist.gov/srm).

The results obtained by methods other than the method laid down in this document, even if calibrated in accordance with 8.1, can, under certain circumstances, differ from those obtained by the method laid down in this document. Hence, in cases of dispute, the method laid down in this document shall be used.

On a given specimen, the average FN as determined by other methods and compared with measurements obtained with the method laid down in this document, shall be within a tolerance band of ±1 FN in the FN range up to 10 FN and this can be proportionally higher as the FN increases beyond 10 FN.

8.2 Maintaining calibration

Instruments shall be checked periodically against secondary standards or primary standards. It is therefore recommended that the organization which uses the instrument ensure that a set of standards be available. It is the responsibility of the user to see that the frequency of checking is adequate to maintain calibration. One standard shall be used for each of the ranges (see Table 4) for which the instrument is to be used. The average value of five measurements at individual positions on the standard shall be within the maximum deviations specified in Table 4.

Table 4 — Maximum allowable deviation in the periodic FN check

FN range	Maximum deviation from the FN value assigned to the standard
0 < FN ≤ 4	±0,5
4 < FN ≤ 10	±0,5
10 < FN ≤ 16	±0,6
16 < FN ≤ 25	±0,8
25 < FN ≤ 50	±5 % of assigned FN
50 < FN ≤ 110	±8 % of assigned FN

9 Procedures used to prepare secondary standards for delta ferrite in austenitic stainless steel weld metal

Coating thickness standards are not suitable for use as primary standards with all types of ferrite measuring instruments. Therefore, a need exists for secondary standards for both calibration and cross-reference of instruments in the laboratory and under shop and field conditions. The first set of secondary standards was developed by Teledyne McKay in the late 1960s. These were based on a buildup of SMAW much like the pad shown in 6.2. They were used to develop the FN system of measuring ferrite as we know it today, replacing the % ferrite system previously used. Teledyne McKay subsequently produced and sold sets of these secondary standards, but ceased doing so in the late 1970s. Therefore, in about 1980, the International Institute of Welding (IIW) requested some organizations, in particular TWI (The Welding Institute, UK) to prepare sets of secondary standards, each consisting of eight blocks of austenitic stainless steel weld metal with Ferrite Numbers in the approximate range 3 FN to 27 FN. An original manufacturing run of 100 sets was prepared by strip cladding. The blocks were produced by VEW-Böhler, Austria, and Ferrite Numbers were assigned to the blocks by TWI. When the original 100 sets had been distributed internationally, a new procedure for producing secondary standards was developed (CNIITMASH, Russia) using centrifugal chill casting to produce large rings in which most of the wall thickness contained a weld-metal–like microstructure. Blocks of dimensions approximately 10 mm × 12 mm × 20 mm were machined from the portion of the ring wall containing the weld-metal–like microstructure. This new procedure was shown, by round robin testing in IIW Commission II, to produce materials suitable for secondary standards over the whole range from near 0 FN to over 100 FN. FN measurements and assignment of the certified FN for each block were carried out at TWI or NIST. The procedures used to prepare the last two types of secondary standards are described in Annexes A and B.

Annex A
(informative)

Manufacture of secondary standards by strip cladding

A.1 Materials

A.1.1 Base metal

The base metal on which the nominally austenitic weld metal was deposited was unalloyed steel type B1 (see ISO 4954) in the form of bars with dimensions 100 mm × 100 mm × 800 mm. The surfaces to be clad were cleaned by free-hand grinding.

A.1.2 Welding consumables

The submerged arc strip cladding process was used. Suitable combinations of strips and fluxes were used so that it was possible to obtain eight FN levels in the range 3 FN to 27 FN in undiluted weld metal. Welding strips consisting of unstabilized, extra-low-carbon austenitic stainless Cr-Ni steel were used, with a cross-sectional area of 60 mm × 0,5 mm. The welding fluxes were agglomerated and contained varying metal powder additions. Before use, the fluxes were rebaked at 300 °C for 1 h.

A.2 Welding procedures

The weld metal in each case consisted of a seven-layer strip clad deposit on the base material, as illustrated in Figure A.1. After each layer, the welding direction was changed. The power supply used had a drooping characteristic. Welding parameters used are given in Table A.1.

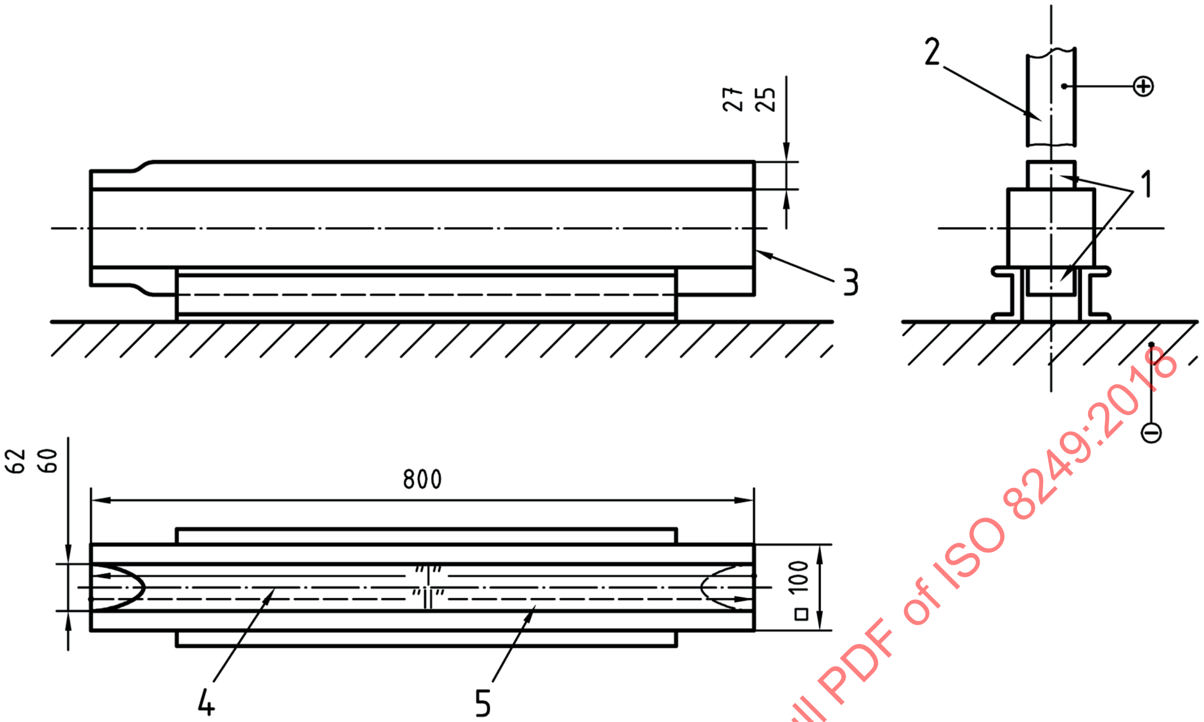
The bead deposition sequence is shown in Figure A.2. To minimize the distortion of the base metal, one side of the bar was first clad with three layers. After turning the bar, three layers were welded on the opposite side.

This procedure was continued with two pass sequences until the last bead.

Table A.1 — Welding parameters

Current	650 A
Voltage	29 V
Travel speed	100 mm/min
Stick out	25 mm
Polarity of the strip	D.C. electrode positive
Preheating	none
Interpass temperature	200 °C maximum
Cooling after welding the last layer	still air

Dimensions in millimetres

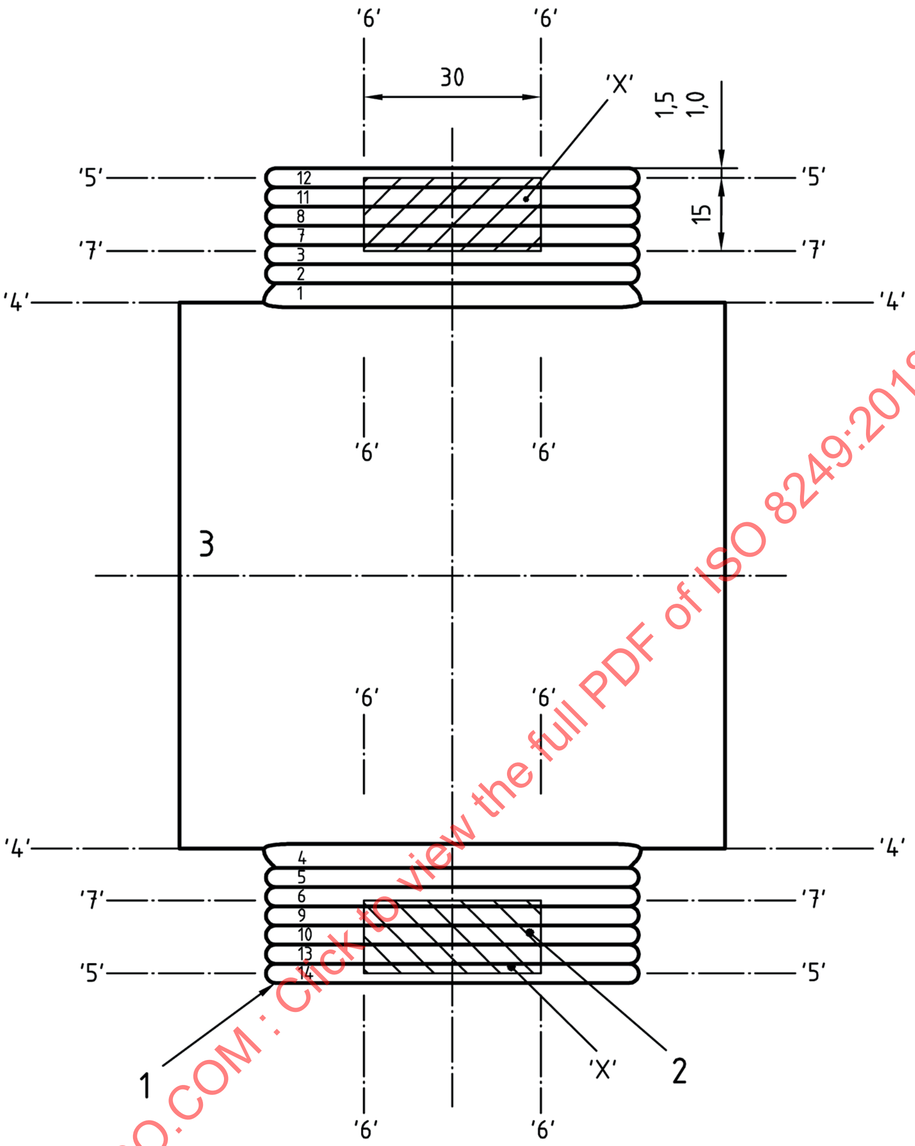


Key

1 weld deposit, 7 layers
2 strip consumable
3 base metal
4 passes 1, 3, 5, 7 on each side
5 passes 2, 4, 6 on each side

Figure A.1 — Method of depositing weld metal for secondary standard by strip cladding

Dimensions in millimetres



Key

1 weld deposit

2 secondary standard

3 base metal

Figure A.2 — Bead deposition and machining sequences for secondary standards by strip cladding

A.3 Machining and marking

A.3.1 Cutting programme

Initially, the end section was cut off, corresponding to lines '1' — '1' in Figure A.3. Chips for the chemical analysis of the seventh layer were taken at the locations marked by 'a' in Figure A.3. Cutting of the other end section followed along lines '2' — '2'.

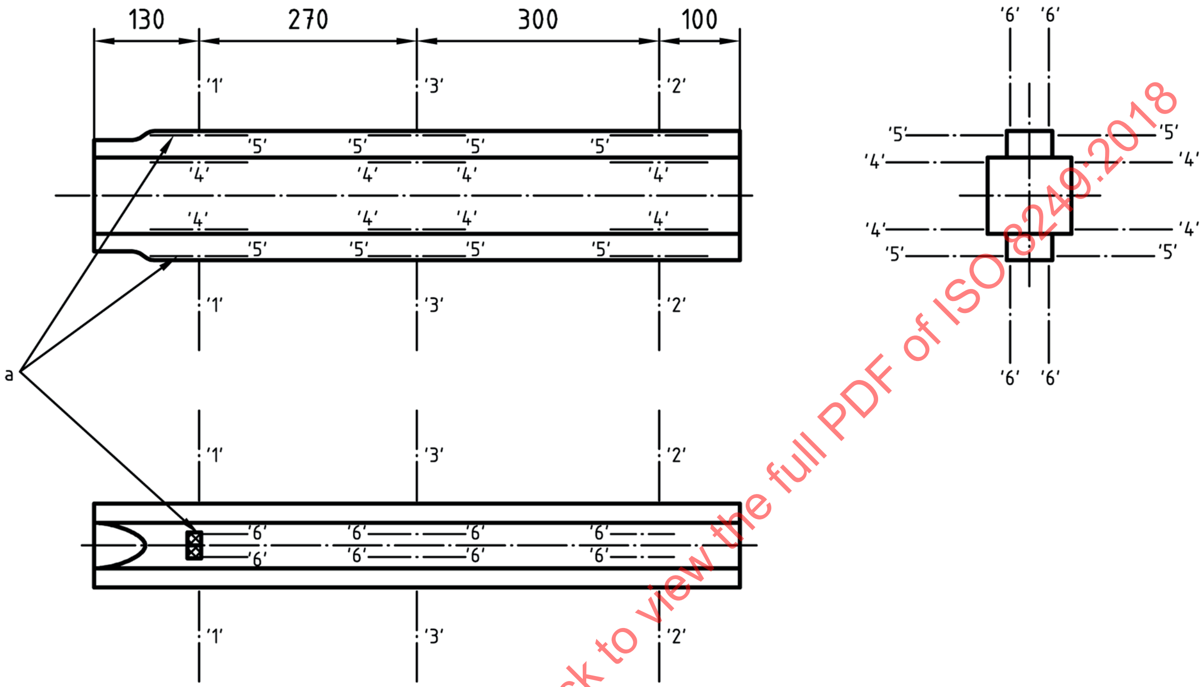
The rest of the bar was divided along lines '3' — '3', and the deposits separated from the base metal along lines '4' — '4'. See Figure A.3.

The rough preparation of the test surfaces followed, along lines '5' — '5' (see X in Figure A.2).

Subsequently, lateral machining along lines '6' —'6' and machining of the bottom surface along lines '7' — '7' was performed (see Figure A.2).

The division of the rough machined weld bars, following the lines '8' — '8', is shown in Figures A.3 and A.4. Subsequently, the single specimens were finished. Thirty specimens could be produced from each bar clad on both sides.

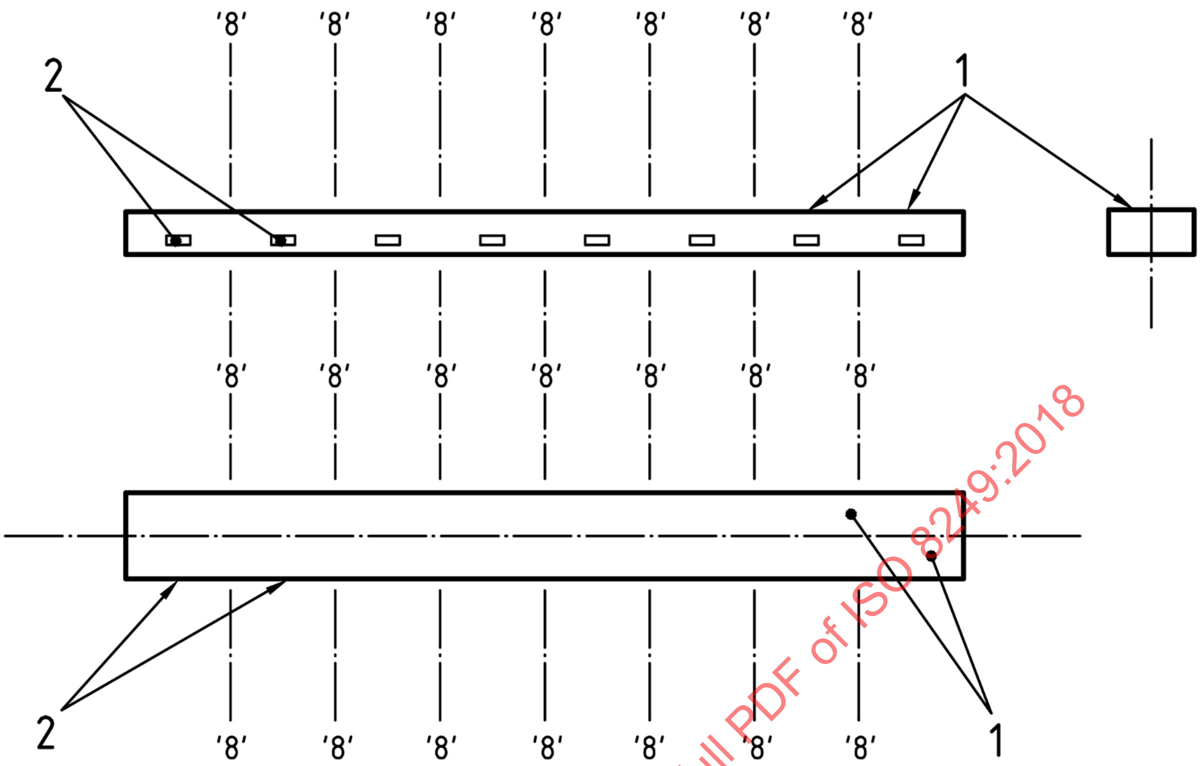
Dimensions in millimetres



Key

a Chips for chemical analysis taken at these points.

Figure A.3 — Cutting sequences for secondary standard by strip cladding



Key

1 test surfaces

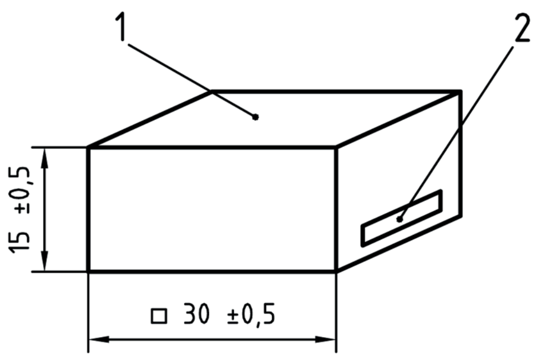
2 marking regions

Figure A.4 — Extraction of individual strip cladding secondary standards

A.3.2 Dimensions, tolerances, surface finish

The dimensions and tolerances of the finished "ferrite secondary standards" are shown in Figure A.5. The test surface was ground with an 8A-80-G-9-V39 grinding disc (see ISO 525). All the other surfaces were rough finished.

Dimensions in millimetres



Key

1 test surface

2 marking region

Figure A.5 — Marking of each strip cladding ferrite secondary standard

A.3.3 Marking for standard identification

The marking of the standards took place on a side face as shown in Figures A.4 and A.5. The marks produced with figure stamps were arranged so that the distance from the test surface was as great as possible.

The reading direction of the marking indicates the welding direction in the seventh layer. The designation of the standards consists of letters and numbers. The letters (A to H) indicate increasing FN values, with the number following indicating the set number.

A.4 Chemical composition

An example of the full chemical analysis of the seventh layer of the deposit (for all the standards) is shown in Table A.2.

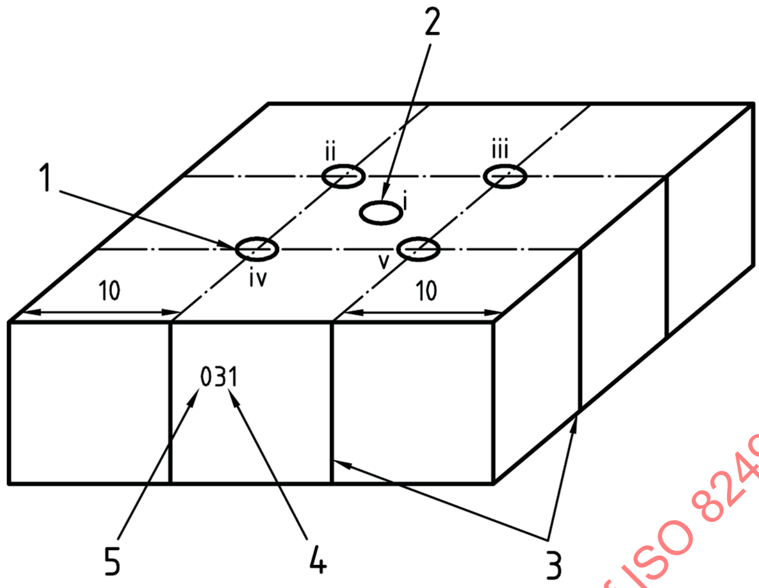
Table A.2 — Example of the chemical composition of seventh layer of strip clad deposits

Seventh layer of deposited metal	Element % (by mass)								
	C	Si	Mn	P	S	Cr	Mo	Ni	Nb
A1 – A15	0,020	1,00	0,78	0,021	0,019	19,62	0,13	11,79	<0,05

A.5 Marking for FN measuring point location

The standards were received at TWI in the conditions described in A.3. FN measurements were to be made at five locations on each standard. The individual samples were thus marked by scribing on the sides as indicated in Figure A.6. The intersections of the imaginary lines joining these marks defined four measuring points. The fifth measuring point was in the centre of the measuring face. The points were identified by i to v as shown in Figure A.6, but these characters were not marked on the block itself.

Dimensions in millimetres



Key

1 points identified by intersection of imaginary lines
2 central point
3 scribed lines
4 standard set number
5 individual standard

Figure A.6 — Marking on each strip cladding secondary standard sample and identification of the five measuring points

A.6 FN measuring instruments and calibration

A.6.1 General

The instruments and procedures used were in conformity with the requirements of this document. Before commencing production and measurement of sets of FN standards for general issue, TWI carried out trials on a prototype set of standards. These demonstrated that FN values ascribed to standards by TWI were consistent with results obtained by other organizations, and also that the strip cladding samples could be used for a range of commercial ferrite measuring instruments.

A.6.2 Instruments used

Two "Magne-gages", manufactured by the American Instrument Company (USA), were used to make measurements on each set of standards. To ensure that the differences between the two instruments were within acceptable limits, at the commencement of the programme both "Magne-gages", after calibration as described in A.6.4, were used to make measurements on all samples comprising one complete set of standards. The two sets of data were well within the range of variation in measurements expected for 95 % of "Magne-gages".

A.6.3 Magnet strength checks

Before the commencement of measurements, the magnets associated with each of the "Magne-gages" were checked to ensure they corresponded to the requirements of this document. This was done by using a laboratory balance to measure tear-off forces from a set of eight USA National Institute of Standards and Technology (NIST, formerly National Bureau of Standards or NBS) coating thickness standards. The standards employed (see Table A.3) were the seven supplied with each individual instrument, together with an eighth one (SRM 1312, nominal thickness 0,2 mm) acquired directly from NIST.

After measurements on every 10 sets of secondary standards, the magnet strengths for each instrument were rechecked to ensure that they still conformed to the requirements.

Magnets were cleaned in accordance with the manufacturer's instructions before each calibration.

Table A.3 — NIST standards employed for "Magne-gage" calibration for strip cladding secondary standards

NIST SRM No.	Nominal coating thickness mm
1312	0,2
1313	0,25
1314	0,38
1315	0,5
1316	0,64
1317	0,76
1318	1,01
1319	1,52

A.6.4 Ferrite Number calibration

The Ferrite Number (FN) versus the white dial reading calibration for each "Magne-gage" instrument was derived in accordance with the procedure laid down in this document. The eight NIST coating thickness standards used were those shown in Table A.3 and a zero point was also determined using a completely non-magnetic material.

Both "Magne-gages" displayed a bend in the calibration at about 13 FN, and thus separate best-fit straight lines (least-squares method) were drawn through the calibration points above and below this level. The equations of these lines were used to derive FN values from white dial readings during subsequent measurement work on the secondary standards.

The maximum tolerances on the positions of individual calibration points were taken as those specified in AWS A4.2. In fact, much better tolerances were achieved in all cases.

A calibration was carried out on each "Magne-gage":

— at the start of each day's work; and

— after the measurement of 4 sets of secondary standards.

A.7 Measuring procedure on secondary standards

A.7.1 Instruments and operators

Four complete sets of readings were taken on each set of eight ferrite secondary standards, by two operators each using both "Magne-gages". Although only two operators were employed on any given set of secondary standards, several operators were employed during the entire measurement programme.

A.7.2 Demagnetization

No attempt was made to demagnetize the standards, as the "Magne-gage" has been reported to be insensitive to pre-magnetization.

A.7.3 Measurements on each ferrite standard

On each individual ferrite standard, three readings were taken at each of the five measurement points, for each operator and "Magne-gage". Non-magnetic jigs were fitted over the standards to aid rapid and accurate location of the measurement points, these consisting of recessed blocks of plastic with suitably sized and positioned holes. The standard was not repositioned between the three individual measurements on any one point.

Each standard thus had a total of 60 "Magne-gage" white dial readings taken from it, twelve for each individual measurement session.

Readings by each operator and "Magne-gage" were completed within one measurement session.

A.7.4 Data recording and analysis

Data from the readings by one "Magne-gage" operator were recorded together with the "Magne-gage" number, FN calibration reference, date and operator's name.

Each set of three white dial readings per individual measurement point was averaged and an FN value produced from the appropriate calibration equation for each point. An average FN value for each standard was produced from the FN values for the five measurement points.

A.7.5 Presentation of results

The presentation of the results on the card to accompany each set of standards was as illustrated in the example in Table A.4.

In addition, a label adjacent to each standard in the box showed the overall average FN value for all measurements on that standard. All values were quoted to 0,1 FN.

Each boxed set of eight standards was also provided with a short booklet, briefly describing the preparation of the set.

Table A.4 — Example of the tabular presentation of results on the card accompanying each box of standards (Secondary weld metal standards, Set 68 – May 1980)

Standard number	Measurement point	"Magne-gage" 1				"Magne-gage" 2				Mean FN for each point	FN overall average
		Operator No. 1		Operator No. 2		Operator No. 1		Operator No. 2			
		FN each point	Mean FN all five points	FN each point	Mean FN all five points	FN each point	Mean FN all five points	FN each point	Mean FN all five points		
A68	1	2,8		2,8		2,7		2,6		2,7	
	2	2,5		2,8		2,6		2,5		2,5	
	3	2,8	2,7	2,8	2,7	2,6	2,6	2,6	2,6	2,7	2,7
	4	2,7		2,6		2,5		2,5		2,6	
	5	2,8		2,7		2,6		2,6		2,7	
B68	1	4,6		4,6		4,5		4,6		4,6	
	2	4,6		4,6		4,5		4,4		4,5	
	3	4,8	4,7	4,8	4,7	4,5	4,5	4,6	4,6	4,7	4,6
	4	4,8		4,8		4,5		4,6		4,7	
	5	4,6		4,6		4,4		4,6		4,5	

Table A.4 *(continued)*

Standard number	Measurement point	"Magne-gage" 1				"Magne-gage" 2				Mean FN for each point	FN overall average
		Operator No. 1		Operator No. 2		Operator No. 1		Operator No. 2			
		FN each point	Mean FN all five points	FN each point	Mean FN all five points	FN each point	Mean FN all five points	FN each point	Mean FN all five points		
C68	1	8,9	8,9	8,8	8,9	8,8	8,7	8,7	8,6	8,8	8,8
	2	8,9		8,9		8,7		8,6		8,8	
	3	8,9		8,8		8,6		8,5		8,7	
	4	9,2		9,1		8,8		8,8		8,9	
	5	8,9		8,9		8,6		8,6		8,7	
D68	1	11,0	11,0	11,0	11,1	10,6	10,5	10,8	10,7	10,9	10,8
	2	10,8		10,9		10,5		10,8		10,7	
	3	11,1		11,2		10,4		10,8		10,9	
	4	10,8		10,8		10,3		10,4		10,6	
	5	11,3		11,6		10,7		10,9		11,1	

Annex B
(informative)

Manufacture of secondary standards by centrifugal chill casting

B.1 Materials

As a result of tests carried out by the Russian delegation to IIW Commission II, it was found that centrifugally chill cast rings with a diameter of approximately 500 mm and wall thickness of approximately 20 mm, of nominally austenitic and duplex ferritic-austenitic chromium-nickel steels, exhibited a weld-metal-like microstructure through most of the wall thickness. In round robin tests among nine laboratories in six countries, it was established that the homogeneity of small blocks machined from rings of ferrite contents from near 0 FN to about 100 FN was excellent over the whole range of interest. Such blocks could thus serve as secondary standards for calibration of various instruments. Due to the homogeneity of the blocks, they could be suitable, in particular, for calibrating instruments utilising magnetic saturation methods for determining a volumetric percentage of ferrite: thus, in principle, it would be possible to establish a relationship between FN and volumetric percent ferrite (FP) over a specific alloy range. Also, due to the homogeneity of the centrifugally cast metal, the preparation of samples having rectangular or cylindrical form and suitable to be certified in both FN and FP (the latter by utilising the magnetic saturation method) is possible. Such samples might then be used for calibrating volumetric and local devices.

Figure B.1 shows a sketch of a centrifugally chill cast ring from which the small blocks were machined. FN was measured at each of five points on each of the six surfaces of the blocks, measuring 10 mm × 12 mm × 20 mm, as shown in Figure B.2, during the round robin evaluations. Figure B.3 shows the overall average measurements for several samples, while Figure B.4 shows the averaged face centre results only. No significant difference can be noted between the face centre results and the overall results, attesting to the homogeneity of the blocks. Thus, one could, in principle, assign both an FN based upon surface measurements, and an FP based on volumetric measurement by magnetic saturation, to a given block or cylinder of this material.

As a result of the homogeneity of these samples as demonstrated in the round robin testing, IIW Commission II, by Resolution No. 4 taken during the 1993 Glasgow Annual Assembly, asked the Russian delegation (the company MLADIS) to proceed with production of rings to provide sets of eight blocks well distributed over the range of near 0 FN to about 30 FN, and sets of eight blocks well distributed over the range of over 30 FN to about 110 FN. After machining, the individual blocks were provided to TWI for assignment of FN, packaging, and distribution to purchasers.

Dimensions in millimetres

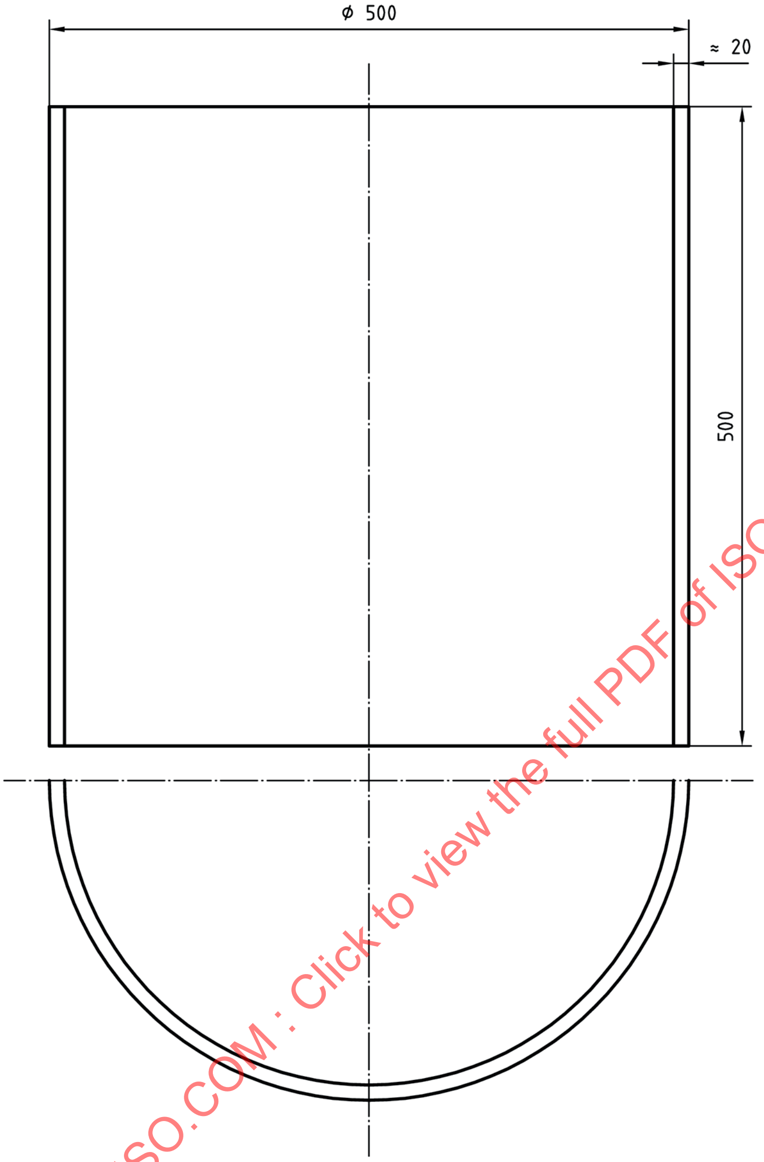
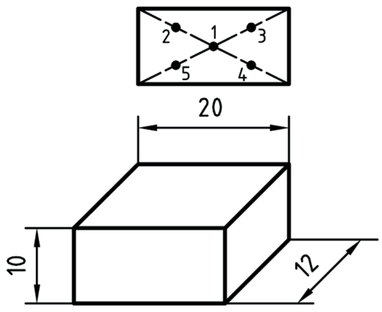
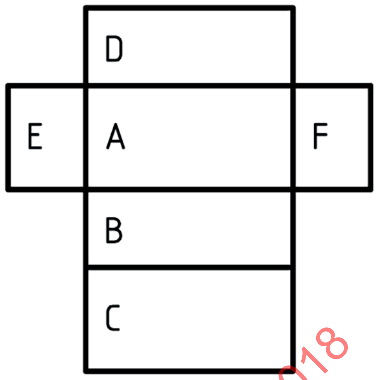


Figure B.1 — Centrifugally chill cast ring for secondary standards

Dimensions in millimetres



a) Measurement positions



b) Faces

Figure B.2 — Dimensions and FN measurement positions on six faces of blocks machined from centrifugally chill cast rings