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Abrasion-resistant cast irons — Classification

Fontes résistant à l'usure par abrasion — Classification

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 21988 was prepared by Technical Committee ISO/TC 25, *Cast irons and pig irons*, Subcommittee SC 6, *High alloy cast irons*.

This International Standard is one of a number that has been prepared by ISO/TC 25/SC 6 under the auspices of ISO/TC 25 for the family of cast irons. The Secretariats of ISO/TC 25 and ISO/TC 25/SC 6 are held by BSI; however, the funding and resources for the Secretariat have been provided by the Cast Metals Federation.

Introduction

This International Standard deals with the classification of abrasion-resistant white cast irons in accordance with their chemical composition and hardness. Such cast irons are widely used in the mining, earth moving, milling and manufacturing industries where high resistance to abrading minerals and other abrading solids is required.

The abrasion resistance of these irons depends upon them having the appropriate structure and hardness for the application. These properties are obtained by careful control of the material composition and the processing route.

Abrasion-resistant cast irons — Classification

1 Scope

This International Standard defines the grades of abrasion-resistant white cast irons. It specifies the grades in terms of:

— chemical composition;

— hardness.

The types of abrasion-resistant white cast irons covered by this International Standard are:

a) unalloyed or low alloy cast irons;

b) nickel-chromium cast irons covering two general types:

4 % Ni 2 % Cr cast irons;
9 % Cr 5 % Ni cast irons;

c) high chromium cast irons covering five ranges of chromium content:

Cr > 11 % to ⩽ 14 %;
Cr > 14 % to ⩽ 18 %;
Cr > 18 % to ⩽ 23 %;
Cr > 23 % to ⩽ 30 %;
Cr > 30 % to ⩽ 40 %.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 15931, *Designation system for cast irons and pig irons*

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
unalloyed or low alloy abrasion-resistant cast iron
cast iron having a structure which consists of eutectic iron carbides in a predominantly pearlitic matrix

3.2
nickel-chromium abrasion-resistant cast iron
cast iron having a structure consisting of either:

— simple eutectic carbides M_3C type (M = Fe, Cr) in a matrix which is predominantly martensitic referred to as 4 % Ni 2 % Cr irons; or

— complex eutectic carbides (M_7C_3 and M_3C) in a matrix which is predominantly martensitic, referred to as 9 % Cr 5 % Ni irons

NOTE 1 Both of these materials can contain some bainite and retained austenite.

NOTE 2 All the grades referred to in this subclause are free of pearlite.

3.3
high chromium abrasion-resistant cast iron
cast iron containing between 11 % and 40 % Cr having a structure consisting of complex carbides in a matrix which, in the hardened condition, is predominantly martensitic, but which can also contain some austenite or other transformation products of austenite

4 Designation

The material shall be designated by symbols denoting the Brinell hardness and the chemical composition (Chromium content, X denoting high Chromium content), in accordance with the designations given in Tables 1 to 3.

NOTE 1 The symbols given in this International Standard comply with the guidance given in ISO/TR 15931.

NOTE 2 According to the designation system given in ISO/TR 15931, the designations of the material grades have been changed.

5 Order information

The following information shall be supplied by the purchaser:

a) the complete designation of the material;

b) any special requirements which have to be agreed upon between the manufacturer and the purchaser by the time of the acceptance of the order.

6 Manufacture

6.1 General

The manufacturing methods for abrasion-resistant cast irons, unless otherwise specified by the purchaser, shall be left to the discretion of the manufacturer. The manufacturer shall ensure that the requirements of this International Standard are met for the material grade specified in the order.

6.2 Heat treatment

Unless otherwise specified by the purchaser, the manufacturer shall supply castings in the condition that he considers to be suitable for the type of casting and the material grade specified.

When it is required to machine castings produced in the high chromium cast iron grades, they shall be ordered in the soft annealed condition. When the purchaser specifies delivery in the soft annealed condition, the subsequent hardening and tempering shall be the responsibility of the purchaser.

NOTE 1 Castings may be supplied in any one of the following conditions:

— as-cast;
— as-cast and tempered;
— hardened;
— hardened and tempered;
— soft annealed;
— soft annealed and hardened;
— soft annealed, hardened and tempered.

NOTE 2 Annex A gives guidance on the types of heat treatment which can be used to obtain the required hardness, structure and properties.

When it is required to machine castings produced in the high chromium cast iron grades, there are two options:

a) Machining castings in the soft annealed condition

When the purchaser specifies delivery in the soft annealed condition, responsibility for any subsequent hardening and tempering operation shall be agreed between the manufacturer and the purchaser at the time of acceptance of the order. There may be some distortion and scaling of the machined castings due to the heat treatment.

b) Machining castings in the as-cast or hardened condition

With appropriate equipment, and cutting tools such as cubic boron nitride (CBN), it is feasible to machine high chromium cast iron grades in the as-cast or hardened condition.

7 Requirements

7.1 Chemical composition

The chemical composition of the grades of abrasion-resistant cast iron shall be in accordance with Tables 1, 2 and 3.

NOTE Unless otherwise specified, other elements may be present, at the discretion of the manufacturer.

7.2 Brinell hardness

The Brinell hardness of the grades of abrasion-resistant cast iron shall be in accordance with Tables 1, 2 and 3.

7.3 Microstructure

Microstructure examination, if required, shall be agreed by the time of acceptance of the order. Where a microstructure examination is agreed, the location for sampling, the methods used to examine the microstructure, and acceptance criteria are subject to that agreement. The microstructure examination shall be performed in accordance with 9.3.

8 Sampling

8.1 Frequency of sampling for chemical analysis

Samples representative of the material shall be produced at a frequency in accordance with the in-process quality assurance procedures used by the manufacturer.

Samples for chemical analysis shall be cast in a manner which ensures that their representative chemical composition can be determined.

8.2 Number and frequency of Brinell hardness tests

Unless otherwise specified by the purchaser by the time of acceptance of the order, the number and frequency of Brinell hardness tests to be carried out shall be in accordance with the in-process quality assurance procedures used by the manufacturer.

In the absence of an in-process quality assurance procedure or any other agreement between the manufacturer and the purchaser, a minimum of one sample shall be produced to confirm the material grade, at a frequency to be agreed between the manufacturer and the purchaser by the time of the acceptance of the order.

9 Testing

9.1 Chemical analysis

The methods used to determine the chemical composition of the material shall be in accordance with recognized standards. Any requirement for traceability shall be agreed between the manufacturer and the purchaser by the time of acceptance of the order.

NOTE Spectrographic, X-ray or wet chemical laboratory techniques are acceptable methods of analysis.

9.2 Hardness test

9.2.1 The Brinell hardness test shall be carried out in accordance with ISO 6506-1.

NOTE Hardness determined by one test method cannot necessarily be compared with that property determined by other test methods. Hardness conversion from other hardness test methods can be done by agreement between the manufacturer and the purchaser. Conversions between Brinell, Vickers and Rockwell C hardness, considered to be applicable to abrasion-resistant cast irons, are given in Annex B, for guidance only.

9.2.2 Each Brinell hardness test shall be carried out on a casting at locations agreed upon between the manufacturer and the purchaser, or on a test block cast-on to the casting itself.

Unless otherwise specified by the purchaser, the dimensions and location of the cast-on test block shall be left to the discretion of the manufacturer.

NOTE A cast-on test block can be used when the size of the casting or the number of castings to be tested makes direct testing on the castings impracticable.

9.2.3 If the test is to be carried out on a cast-on test block, the latter shall not be removed from the casting until after any required heat treatment has been carried out.

9.2.4 When castings are too large or too difficult to be tested in a conventional hardness testing machine, or when there is need for on-line inspection of a large number of castings, a portable hardness testing device may be used. When using portable hardness testing devices, its accuracy shall be validated using a calibrated test block. The use of such devices shall be agreed upon between the manufacturer and the purchaser by the time of acceptance of the order.

9.3 Microstructure sample

Microstructure examination shall be performed on a sample cut from a casting, or from a separately cast or cast-on sample. The sample shall have comparable solidification and cooling conditions as the critical sections of the casting.

NOTE Descriptions of typical microstructures are given for guidance in Annex D.

10 Retests

10.1 Need for retests

Retests shall be carried out if a test is not valid (see 10.2).

Retests are permitted to be carried out if a test result does not meet the specified requirements for the specified grade (see 10.3).

10.2 Test validity

A test is not valid if there is:

a) a faulty mounting of the test piece or defective operation of the test machine;

b) a defective test piece because of incorrect pouring or incorrect machining.

In the above cases, a retest shall be taken from the same sample or from a duplicate sample cast at the same time to replace those invalid test results.

The result of the retest shall be used.

10.3 Nonconforming test results

If any test gives results which do not conform to the specified requirements, for reasons other than those given in 10.2, the manufacturer shall have the option to conduct retests. If the manufacturer conducts retests, two retests shall be carried out for each failed test.

If the results of both retests meet the specified requirements, the material shall be deemed to conform to this International Standard.

If the results of one or both retests fail to meet the specified requirements, the material shall be deemed not to conform to this International Standard.

10.4 Heat treatment of castings

Unless otherwise specified, in the case of castings in the as-cast condition with mechanical properties not in conformance with this International Standard, a heat treatment may be carried out.

In the case of castings which have undergone a heat treatment and for which the test results are not satisfactory, the manufacturer shall be permitted to re-heat-treat the castings and the representative samples. In this event, the samples shall receive the same number of heat treatments as the castings.

In the results of the tests carried out on the test pieces machined from the re-heat-treated samples are satisfactory, then the re-heat-treated castings shall be regarded as conforming to this International Standard.

The number of re-heat treatment cycles shall not exceed two.

Table 1 — Brinell hardness and chemical composition of unalloyed or low alloy abrasion-resistant cast iron

Material designation	Brinell hardness HBW	Chemical composition in % (mass fraction)			
Symbol	min.	C	Si	Mn	Cr
ISO 21988/JN/HBW340	340	2,4 to 3,9	0,4 to 1,5	0,2 to 1,0	max. 2,0
ISO 21988/JN/HBW400	400	2,4 to 3,9	0,4 to 1,5	0,2 to 1,0	max. 2,0

Table 2 — Brinell hardness and chemical composition of nickel-chromium abrasion-resistant cast irons

Material designation	Brinell hardness HBW	Chemical composition in % (mass fraction)						
Symbol	min.	C	Si	Mn	P	S	Ni	Cr
ISO 21988/JN/ HBW480Cr2	480	2,5 to 3,0	max. 0,8	max. 0,8	max. 0,10	max. 0,10	3,0 to 5,5	1,5 to 3,0
ISO 21988/JN/ HBW500Cr9	500	2,4 to 2,8	1,5 to 2,2	0,2 to 0,8	0,06	0,06	4,0 to 5,5	8,0 to 10,0
ISO 21988/JN/ HBW510Cr2	510	3,0 to 3,6	max. 0,8	max. 0,8	max. 0,10	max. 0,10	3,0 to 5,5	1,5 to 3,0
ISO 21988/JN/ HBW555Cr9	555	2,5 to 3,5	1,5 to 2,5	0,3 to 0,8	max. 0,08	max. 0,08	4,5 to 6,5	8,0 to 10,0
ISO 21988/JN/ HBW630Cr9	630	3,2 to 3,6	1,5 to 2,2	0,2 to 0,8	0,06	0,06	4,0 to 5,5	8,0 to 10,0

NOTE 1 For guidance on the relationship between casting thickness and composition, see Tables C.1 and C.2.

NOTE 2 Both toughness and resistance to repeated impact increase as the carbon content decreases. Resistance to abrasion increases as the carbon content increases.

NOTE 3 For castings with alloy contents at the low end of the range and supplied in the as-cast condition or in the case of castings with greater wall thickness, it can be difficult to obtain the minimum hardness. The requirements for such castings should be agreed upon between the manufacturer and the purchaser.

Table 3 — Brinell hardness and chemical composition of high chromium abrasion-resistant cast irons

Material designation	Brinell hardness	Chemical composition in % (mass fraction)								
Symbol	HBW min.	C	Si max.	Mn	P max.	S max.	Cr	Ni max.	Mo max.	Cu max.
ISO 21988/JN/ HBW555XCr13	555	> 1,8 to 3,6	1,0	0,5 to 1,5	0,08	0,08	11,0 to 14,0	2,0	3,0	1,2
ISO 21988/JN/ HBW555XCr16	555	> 1,8 to 3,6	1,0	0,5 to 1,5	0,08	0,08	14,0 to 18,0	2,0	3,0	1,2
ISO 21988/JN/ HBW555XCr21	555	> 1,8 to 3,6	1,0	0,5 to 1,5	0,08	0,08	18,0 to 23,0	2,0	3,0	1,2
ISO 21988/JN/ HBW555XCr27	555	> 1,8 to 3,6	1,0	0,5 to 2,0	0,08	0,08	23,0 to 30,0	2,0	3,0	1,2
ISO 21988/JN/ HBW600XCr35	600	> 3,0 to 5,5	1,0	1,0 to 3,0	0,06	0,06	30,0 to 40,0	1,0	1,5	1,2
ISO 21988/JN/ HBW600XCr20Mo2Cu	600	> 2,6 to 2,9	1,0	1,0	0,06	0,06	18,0 to 21,0	1,0	1,4 to 2,0	0,8 to 1,2

NOTE 1 The carbon range within each material designation *should* be agreed between the manufacturer and the purchaser to meet the casting service requirements. Both toughness and resistance to repeated impact increase as the carbon content decreases. The following carbon ranges are given as a guide for selecting the appropriate carbon range. The lower C range (C > 1,8 to 2,4) will provide good toughness and shock resistance. The intermediate C range (C > 2,4 to 3,2) will provide a good combination of toughness and shock resistance. The higher C range (C > 3,2 to 5,5) will provide higher wear resistance with reduced toughness and shock resistance.

NOTE 2 The structure of high chromium abrasion-resistant cast irons depends on the cooling rate and is therefore sensitive to the casting thickness. To obtain specific properties, within the ranges in Table 3, some adjustments to the percentage of the alloying elements given may be necessary depending upon the casting dimensional variations.

NOTE 3 For castings with alloy contents at the lower end of the range and supplied in the as-cast condition or for castings with greater thickness, it can be difficult to obtain the minimum hardness. The requirements for such castings should be agreed between the manufacturer and the purchaser.

NOTE 4 The corrosion resistance increases as chromium content increases and/or carbon content decreases.

Annex A
(informative)

Heat treatment

A.1 Unalloyed or low alloy cast irons

Unalloyed or low alloy cast iron castings are normally supplied in the as-cast condition and do not require heat treatment.

Should a heat treatment be required to improve machinability, this should be agreed between the manufacturer and the purchaser by the time of acceptance of the order.

A.2 Nickel-chromium cast irons

A.2.1 4 % Ni 2 % Cr cast irons

4 % Ni 2 % Cr cast irons are frequently supplied and used in the as-cast condition. For certain applications castings can benefit from a heat treatment at 250 °C to 300 °C for 8 h to 16 h followed by air or furnace cooling. This treatment relieves residual casting stresses.

For improved resistance to repeated impact, to help the complete breakdown of as-cast austenite, castings can be tempered at the higher temperature of 425 °C to 475 °C.

A typical cycle is as follows:

— heat treatment at 425 °C to 475 °C for 4 h to 6 h followed by air or furnace cooling; and then

— heat treatment at 250 °C to 300 °C for 8 h to 16 h followed by air or furnace cooling.

A.2.2 9 % Cr 5 % Ni cast irons

9 % Cr 5 % Ni cast iron castings can be heat treated in one of two ways depending on casting complexity.

a) For simple shapes, a single heat treatment is adequate, involving heat treatment at 800 °C to 850 °C for 6 h to 12 h followed by air or furnace cooling.

b) Where maximum resistance to repeated impact is required, castings can benefit from a heat treatment at 800 °C to 850 °C for 8 h to 16 h followed by air or furnace cooling and then tempering at 250 °C to 300 °C for 8 h to 12 h with air or furnace cooling.

NOTE Air cooling from 850 °C to 800 °C may be undesirable for heavy sections of complex design as cracking may occur.

A.3 High chromium cast irons

A.3.1 General

High chromium cast iron castings can be supplied in either the as-cast or heat-treated condition. An appropriately balanced combination of chemical composition and heat treatment is necessary for satisfactory results. Typical heat treatments are hardening, tempering, soft annealing and annealing.

NOTE A high risk of cracking exists during heat treatment of large castings, particularly with large changes in section thickness. If cracking occurs, it generally happens during heat-up, even with a slow heat-up rate.

A.3.2 Hardening

Hardening involves slowly heating up the casting to a defined temperature range and holding for a time appropriate to its thickness and chemical composition, followed by rapid cooling. Only simple shaped castings can be oil quenched without the risk of cracking, so rapid cooling is most frequently carried out by air/gas cooling. The air/gas cooling can be carried out by fan cooling, forced gas or atomised liquid spray techniques.

It can be necessary to cool complex shaped castings in still air. Under such circumstances, it is important that the material chemical composition makes provision for sufficient hardenability.

A typical hardening cycle is:

— slowly heating up to a temperature within the range of 900 °C to 1 050 °C;

— holding for a determined period of time; and

— then rapidly cooling.

A.3.3 Tempering

Tempering may be required in order to transform any retained austenite to martensite to reduce residual stresses or to reduce the hardness of the material.

A typical tempering cycle involves:

— slowly heating up to a temperature within the range of 200 °C to 550 °C;

— holding for a period of time appropriate to the thickness;

— followed by air or furnace cooling.

A.3.4 Soft annealing

If casting hardness below HBW 378 is required (e.g. to facilitate machining), soft annealing can be carried out.

An example of a soft annealing method is:

— slowly heating up to a temperature within the range of 920 °C to 975 °C;

— holding for at least 1 h;

— then slowly cooling down in the furnace to about 810 °C; and

— then further cooling down to 600 °C at a rate not exceeding 55 K/h;

— followed by air or furnace cooling.

A.3.5 Annealing

If castings require annealing then a typical annealing involves slowly heating up to a temperature of 700 °C to 750 °C for a minimum of 4 h, and then slowly cooling in the furnace to 600 °C, following by air or furnace cooling.

Annex B
(informative)

Conversion between Brinell, Vickers and Rockwell C hardness

B.1 Conversion values

Table B.1 shows the approximate hardness conversions between Brinell, Vickers and Rockwell C for abrasion-resistant cast irons.

Table B.1 — Approximate conversions between Brinell, Vickers and Rockwell C hardness for abrasion-resistant cast irons

Brinell [a] HBW	Vickers [b] HV	Rockwell [c] HRC
340	350	34
378	400	39
420	450	44
465	500	47
480	520	48
510	550	50
555	600	53
595	650	56
640	700	58
—	750	60

[a] The maximum hardness range for the Brinell hardness test is 650 HBW, see ISO 18265.

[b] Unless otherwise agreed, the minimum scale to be used is HV 30.

[c] The use of the Rockwell C hardness test is not recommended for determining the hardness of abrasion-resistant cast irons with hardness values lower than 39 HRC.

Annex C
(informative)

Relationship between casting thickness and chemical composition for nickel-chromium cast irons

Annex C gives the relationship between casting thickness and chemical composition for nickel-chromium cast irons.

Tables C.1 and C.2 show typical chemical compositions, which ensure the formation of a white cast iron and a pearlite-free matrix structure depending upon casting wall thickness.

Table C.1 — Typical relationship between casting thickness and chemical composition for nickel-chromium abrasion-resistant cast irons (4 % Ni 2 % Cr cast irons)

Casting thickness t	Chemical composition in % (mass fraction)			
mm	Si	Mn	Ni	Cr
$t \leqslant 25$	0,50	0,40	3,4	1,8
$> 25 < t \leqslant 50$	0,40	0,50	3,8	2,0
$> 50 < t \leqslant 100$	0,40	0,50	4,2	2,5
$100 < t$	0,40	0,60	4,5	3,0
NOTE Higher nickel contents should be used if casting wall thickness significantly above 100 mm is involved.				

Table C.2 — Typical relationship between casting thickness and chemical composition for nickel-chromium abrasion-resistant cast irons (9 % Cr 5 % Ni cast irons)

Casting thickness t	Chemical composition in % (mass fraction)			
mm	Si	Mn	Ni	Cr
$t \leqslant 25$	1,90	0,40	4,5	8,5
$> 25 < t \leqslant 50$	1,80	0,50	5,0	9,0
$> 50 < t \leqslant 100$	1,80	0,50	5,0	9,0
$100 < t$	1,60	0,60	5,5	9,5
NOTE Higher nickel contents should be used if casting wall thickness significantly above 100 mm is involved.				

Annex D
(informative)

Typical microstructures of abrasion-resistant cast iron

D.1 Unalloyed or low alloyed abrasion-resistant cast irons

The microstructure consists of continuous hard iron carbides and pearlite. The structure is normally free of graphite except where its occurrence is unavoidable, as in heavy slowly cooled sections, or where its presence is specifically requested or permitted by the purchaser.

D.2 Nickel-Chromium abrasion-resistant cast irons

The microstructure consists of either eutectic carbides M_3C or complex carbides M_7C_3 and M_3C (M = Fe, Cr) in a matrix which consists mainly of martensite and possibly some bainite, together with some retained austenite.

D.3 High Chromium abrasion-resistant cast irons

The microstructure exhibits two general types:

a) Hypoeutectic, consisting of eutectic carbides in a matrix of primary austenitic dendrites and eutectic austenite

   During hardening, the austenite phase transforms to predominantly martensite containing a fine dispersion of secondary carbides. The structure may also contain retained austenite, and other transformation products of austenite.

b) Hypereutectic, consisting of primary carbides and eutectic carbides in a eutectic austenite matrix

   During hardening, the austenite phase transforms to predominantly martensite containing a fine dispersion of secondary carbides. The structure may also contain retained austenite, and other transformation products of austenite.

In these irons, both the primary carbides and eutectic carbides are acicular in shape with an aspect ratio in the range 10:1 to 100:1. The long axis of the carbide particles may be normal to the casting surface (except towards the centre of thick castings), and hexagonal in cross-section.

Annex E
(informative)

Cross references to other standards

Table E.1 — Cross references to other standards

Grade	ISO 21988:2005	EN 12513:2001	ASTM A532:1999	AS 2027-2002	DIN 1695:1981
Low alloyed, unalloyed, Nickel-chromium					G-X 300 NiMo 3 Mg
	ISO 21988/JN/HBW340	EN-GJN-HV350		U-350	
	ISO 21988/JN/HBW400			U-400	
			Ni-Cr-GB		
	ISO 21988/JN/HBW480Cr2	EN-GJN-HV520	Ni-Cr-Lc	NiCr2-500	G-X 260 NiCr 4 2
	ISO 21988/JN/HBW510Cr2	EN-GJN-HV550	Ni-Cr-Hc	NiCr1-550	G-X 330 NiCr 4 2
	ISO 21988/JN/HBW500Cr9			NiCr4-500	
	ISO 21988/JN/HBW555Cr9	EN-GJN-HV600	Ni-HiCr	NiCr4-600	G-X 300 CrNiSi 9 5 2
	ISO 21988/JN/HBW630Cr9			NiCr4-630	
High alloyed	ISO 21988/JN/HBW555XCr13	EN-GJN-HV600(XCr11)	12 % Cr		
					G-X 300 CrMo 15 3
	ISO 21988/JN/HBW555XCr16	EN-GJN-HV600(XCr14)	15 % Cr-Mo	CrMo 15 3	G-X 300 CrMoNi 15 2 1
	ISO 21988/JN/HBW555XCr21	EN-GJN-HV600(XCr18)	20 % Cr-Mo	CrMo 20 1	G-X 260 CrMoNi 20 2 1
	ISO 21988/JN/ HBW600XCr20Mo2Cu			CrMoCu 20 2 1	
	ISO 21988/JN/HBW555XCr27	EN-GJN-HV600(XCr23)	25 % Cr	Cr 27 LC and Cr 27 HC	G-X 260 Cr 27
					G-X 260 CrMo 27 1
	ISO 21988/JN/HBW600XCr35			Cr 35	

Bibliography

[1] ISO 18265, *Metallic materials — Conversion of hardness values*

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