
British Standard

Magnetic materials

Part 1. Classification

Matériaux magnétiques
Partie 1. Classification

Magnetische Werkstoffe
Teil 1. Einteilung

Foreword

This British Standard has been prepared under the direction of the Iron and Steel and Non-Ferrous Metals Standards Committees.

This British Standard is technically equivalent to IEC Publication 404-1 : 1979, 'Magnetic materials, Part 1 Classification', published by the International Electrotechnical Commission (IEC).

This Part of BS 6404 is the first Part of a series of British Standards based on the IEC Publication 404 series, 'Magnetic materials' published by the International Electrotechnical Commission. The Part numbers of the British Standard follow the Parts of the IEC Publication. Other Parts of this British Standard currently in course of preparation are as follows:

- Part 2 Methods of measurement of magnetic, electrical and physical properties of magnetic sheet and strip.
- Part 3 Methods of measurement of specific total losses of magnetic sheet and strip by means of a single sheet tester.

Additional Parts of IEC Publication 404 will be published and are expected to provide the basis for additional Parts of this British Standard.

For ease of reproduction the IEC text has been used as the basis for this British Standard. Some terminology and certain conventions are not identical with those used in British Standards. However, the Scope from IEC Publication 404-1 has been rewritten to comply with the requirements for the presentation of British Standards. Thereafter, the clause numbers follow those given in IEC Publication 404-1. This is because the clause numbers are also used to classify the materials.

In addition, the tables have not been numbered or given headings. However, where relevant, references to ISO Standards and IEC Publications have been changed to refer to British Standards.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

	Page
Foreword	Inside front cover
0. Introduction	2
1. Scope	2
2. Classification of magnetic materials	2

MAGNETICALLY SOFT MATERIALS

Section and clause	
A IRONS	2
B LOW CARBON MILD STEELS	4
B2. Flat material	4
C SILICON STEELS	5
C1. Solid material	5
C2. Flat material	6
C21. Isotropic steels	6
C22. Anisotropic steels	8
C23. Thin silicon steels	9
D OTHER STEELS	10
D1. Solid material	10
D11. Cast solid steels	10
D12. Forged solid steels	12
D2. Flat material	13
E NICKEL-IRON ALLOYS	14
E1. Nickel content 72% to 83%	14
E2. Nickel content 54% to 68%	15
E3. Nickel content 45% to 50%	16
E4. Nickel content 35% to 40%	18
E5. Nickel content 30% (approximately)	19
F IRON-COBALT ALLOYS	19
F1. Cobalt content 47% to 50%	19
F2. Cobalt content 35%	21
F3. Cobalt content 23% to 27%	22
G OTHER ALLOYS	23
G1. Aluminium-iron alloys	23
G2. Aluminium-silicon-iron alloys	24
H MAGNETICALLY SOFT FERRITES	25
H1. General	25
H2. Physical characteristics	25
H3. Main applications	26

MAGNETICALLY HARD MATERIALS

R MAGNETICALLY HARD ALLOYS	27
R1. Alloys of aluminium-nickel-cobalt-iron-titanium	27
R2. Platinum-cobalt alloys	28
R3. Cobalt-iron-vanadium alloys	29
R4. Copper-nickel-iron alloys	30
R5. Rare earth-cobalt alloys	31
S MAGNETICALLY HARD CERAMICS	32
S1. Hard ferrites	32
T OTHER MAGNETICALLY HARD MATERIALS	34
T1. Martensitic steels	34

British Standard

Magnetic materials

Part 1. Classification

0. Introduction

This Part of BS 6404 is a classification of commercially available magnetic materials. It should not be read as a technical specification.

The term 'magnetic materials' denotes substances where the application requires the existence of ferromagnetic or ferrimagnetic properties.

In this standard, the classification of magnetic materials is based upon the generally recognized existence of two * main groups of products:

- (a) soft magnetic materials (coercivity ≤ 1000 A/m);
- (b) hard magnetic materials (coercivity > 1000 A/m).

Within these main groups, the classification when appropriate recognizes the following characteristics:

- (1) the main alloying element and the physical state and properties of the material;
- (2) when possible and convenient, the relationship between these characteristics is identified.

A classification by specific areas of application cannot be applied to all materials because different materials can very often be used for the same application depending on the characteristics required.

1. Scope

This Part of BS 6404 classifies commercially available magnetic materials. It also gives information on chemical composition, available forms, physical characteristics and main applications for each of the materials listed.

Note. — The titles of the publications referred to in this standard are listed on the inside back cover.

2. Classification of magnetic materials

In the general classification of magnetic materials which follows, the nomenclature and values employed are those sanctioned by usage.

MAGNETICALLY SOFT MATERIALS

A IRONS

A0.1. General

A0.1.1 Chemical composition

The basic constituent of these materials is iron and they are often referred to as "commercially pure" or "magnetically soft" irons. Elements that adversely affect the remanence, coercivity, saturation flux density and stability of the magnetic properties are controlled to

* In a future edition of this standard, it is proposed to introduce semi-hard magnetic materials as an additional group.

produce the required magnetic properties for the proposed application. The amounts of the most significant elements, other than iron, when they are present in these materials are characteristically within the following ranges:

Ranges of chemical composition (%)

C	Si	Mn	P	S	Al	Ti
0.005 to 0.030	0.002 to 0.10	0.03 to 0.20	0.005 to 0.015*	0.010 to 0.030*	0.002 to 0.08	0.002 to 0.10

* For improved free machining capability, the upper limits for P and S may be higher than indicated in the table.

A0.1.2 *Basis of sub-classification*

The recommended sub-classification is based on coercivity values.

A0.1.3 *Available forms*

This material is available in a wide variety of forms. It may be supplied as slabs, billets, ingots and forgings; as hot-rolled bar in rectangular and square cross-sections; as rod in round, hexagonal and octagonal cross-sections; in cold-rolled and drawn forms as bar, rod and wire; as flat-rolled sheet and strip.

A0.2. **Physical characteristics**

In addition to the values of coercivity, a more complete definition of these materials can be based on the following characteristics.

- Magnetic:** Saturation flux density; permeability for various field strengths; stability of characteristics with time;
- Mechanical:** Hardness; suitability for punching operations; free machining capability; deep drawing properties, tensile strength;
- Metallurgical state:** Hot- or cold-worked; forged; deep drawn.

Note. — For material which has been mechanically worked, the magnetic properties used as the basis of sub-classification will be achieved only by annealing in accordance with the recommendations of the manufacturer.

A0.3 **Main applications**

The main applications are in d.c. relays, loudspeakers, electromagnets, magnetic clutches, brakes, parts for magnetic circuits in instruments and control apparatus, as well as for pole pieces and other d.c. parts for generators and motors.

B LOW CARBON MILD STEELS

B2. FLAT MATERIAL

B2.0.1. General

B2.0.1.1 *Chemical composition*

The basic constituent of these materials is iron containing unavoidable impurities, together with a low level of other elements which may arise from additions necessitated during the manufacturing process. These materials usually require final annealing treatment after punching to develop their full magnetic properties.

B2.0.1.2 *Basis of sub-classification*

The recommended sub-classification is based on the specific total losses which are a function of thickness and are normally measured at magnetic flux density values of 1.0 T or 1.5 T and at normal industrial power frequencies.

B2.0.1.3 *Available forms*

The material is normally supplied in the form of coils or sheets.

B2.0.2 Physical characteristics

In addition to specific total losses, a fuller definition of these materials can be based on the following properties.

Magnetic: Flux density at various values of field strength;

Mechanical: Suitability for punching operations, surface condition, stacking factor;

Metallurgical state: Hard state — i.e. as processed or cold-rolled.
Annealed and finally cold-worked.
Annealed state.

Note. — For material delivered in the hard state or annealed and finally cold-worked, the sub-classification is based on the total specific losses measured after heat treatment according to the recommendations of the manufacturer.

Dimensions: Thickness, width and (as required) length.

Recommended nominal thicknesses for these materials are 0.47 mm, 0.50 mm, 0.63 mm, 0.65 mm and 1.0 mm.

Magnetic measurements shall be made in accordance with BS 6404 : Part 2.

Typical ranges of values of specific total loss, after annealing, for two commonly-used thicknesses are as shown in the table.

Nominal thickness (mm)	Ranges of specific total loss (W/kg) at			
	50 Hz		60 Hz	
	1.0 T	1.5 T	1.0 T	1.5 T
0.50	2.6 to 4.3	5.8 to 10.5	3.3 to 5.6	7.3 to 13.3
0.65	2.8 to 5.0	7.0 to 12.0	3.6 to 6.3	8.2 to 15.5

B2.0.3 Main applications

The materials are used in the manufacture of laminated cores for electrical apparatus and especially small rotating machines.

C SILICON STEELS

C1. SOLID MATERIAL

C1.0.1 General

C1.0.1.1 Chemical composition

The basic constituent of these materials is iron in which the main alloying element is silicon up to 5%.

C1.0.1.2 Basis of sub-classification

The recommended sub-classification is based on the electrical resistivity which in this case is a function of silicon content.

C1.0.1.3 Available forms

These materials are available as hot-rolled and cold-drawn bar, wire, ground bar and forging billets and require heat treatment after mechanical working to achieve the required magnetic properties.

C1.0.2 Physical characteristics

In addition to electrical resistivity for which typical ranges are given in the table, a more complete definition of these materials can be based on the following characteristics:

Magnetic:	Saturation flux density; remanence; coercivity;
Mechanical:	Machinability; ductility; hardness;
Metallurgical state:	Hot- or cold-worked; annealed to produce required magnetic characteristics.

Silicon content	$\leq 1\%$	$> 1\% \leq 2.5\%$	$> 2.5\% \leq 5\%$
Resistivity $\mu\Omega \text{ m}$	0.13 to 0.25	0.25 to 0.40	0.40 to 0.65

C1.0.3 Main applications

The main applications are for the magnetic circuits of relays, magnetic clutches, gyro housings, magnetic pole pieces, and stepping motors.

C2. FLAT MATERIAL

C21. ISOTROPIC* (NON-ORIENTED) STEELS FOR USE AT INDUSTRIAL FREQUENCIES

C21.0.1 General

C21.0.1.1 Chemical composition

The basic constituent of these materials is iron. The main alloying element is silicon, whose content may be between 0.4% and 5.0%. Other alloying elements, namely aluminium, may also be present. The material also contains unavoidable impurities, together with a low level of other elements which may arise from additions necessitated during the manufacturing process.

C21.0.1.2 Basis of sub-classification

The recommended sub-classification is based on the specific total losses which are a function of thickness and normally measured at magnetic flux density values of 1.0 T or 1.5 T and at industrial power frequencies.

When the application demands it (e.g. relays), it may be more appropriate for the sub-classification to be based on coercivity.

C21.0.1.3 Available forms

The material is normally supplied in the form of coil and sheet.

* This describes a material which is substantially isotropic and deliberately processed to be so.

C21.0.2 Physical characteristics

In addition to the values of specific total losses, a more complete definition of these materials can be based on the following characteristics:

Magnetic: Flux density for different values of magnetizing field; anisotropy;

Electrical: Surface insulation, resistivity;

Mechanical: Suitability for punching operations; ductility (determined by the alternate bend test); tensile strength; surface condition and finish; stacking factor; flatness; edge camber;

Metallurgical state: Hard state, i.e. as processed; cold-rolled; annealed and finally cold-worked; annealed state.

Note. — For material delivered in the hard state or annealed and finally cold-worked, the sub-classification is based on the specific total losses measured after heat treatment according to the recommendations of the manufacturer.

Dimensions: Thickness, width and (as required) length.

The values of nominal thickness normally recommended are 0.35 mm, 0.47 mm, 0.50 mm, 0.63 mm and 0.65 mm. If a greater thickness is necessary, the value of 1.0 mm is recommended.

Magnetic measurements shall be made in accordance with BS 6404 : Part 2.

Note.— The density values to be used for magnetic measurements should be the subject of agreement at the time of enquiry and order.

Typical ranges of values of specific total loss, after final annealing, for three commonly-used thicknesses are shown in the following table:

Nominal thickness (mm)	Ranges of specific total loss (W/kg) at			
	50 Hz		60 Hz	
	1.0 T	1.5 T	1.0 T	1.5 T
0.35	0.8 to 1.5	2.0 to 3.6	1.0 to 1.9	2.5 to 4.6
0.50	1.0 to 3.6	2.5 to 8.6	1.25 to 4.5	3.2 to 11.0
0.65	1.2 to 4.2	3.0 to 10.0	1.5 to 5.3	3.8 to 13.0

C21.0.3 Main applications

These materials are used mainly in the magnetic circuits of electrical apparatus, particularly in the parts of rotating machines in which the flux is not unidirectional. They may also be used in electromagnetic relays.

C22. ANISOTROPIC* (ORIENTED) STEELS FOR USE AT INDUSTRIAL FREQUENCIES

C22.0.1 **General**C22.0.1.1 *Chemical composition*

The basic constituent of these materials is iron and the main alloying element is silicon (approximately 3%), together with unavoidable impurities and low levels of other elements which may arise from additions necessitated during the manufacturing process. This type of magnetic material possesses anisotropic properties (orientation) such that the direction parallel to the axis of rolling shows the lowest values of specific total losses and the highest permeability. These properties are sensitive to mechanical treatment, and stress relief annealing may be used to optimize the inherent properties.

C22.0.1.2 *Basis of sub-classification*

The recommended sub-classification is based on the specific total losses, which are a function of thickness and of the degree of orientation, and are normally measured at magnetic flux density values of 1.5 T or 1.7 T and at industrial power frequencies.

C22.0.1.3 *Available forms*

The material is normally supplied in the form of coils or sheets.

C22.0.2 **Physical characteristics**

In addition to the values of specific total losses, a more complete definition of these materials can be based on the following characteristics:

<i>Magnetic:</i>	Flux density for different values of magnetizing field;
<i>Electrical:</i>	Surface insulation; resistivity;
<i>Mechanical:</i>	Ductility (determined by the alternate bend test); surface condition and finish; stacking factor; flatness; edge camber;
<i>Metallurgical state:</i>	Annealed and fully recrystallized;
<i>Dimensions:</i>	Thickness, width and (if required) length.

The values of nominal thickness normally recommended are: 0.27 mm, 0.30 mm and 0.35 mm.

Magnetic measurements shall be made in accordance with BS 6404 : Part 2. The density used for calculations is normally 7.65 kg/dm³ and test pieces shall be taken parallel to the axis of rolling and, before measurement, undergo stress relief annealing in accordance with the recommendations of the manufacturer.

* This describes a material which is substantially anisotropic and deliberately processed to be so.

Typical ranges of values of specific total loss, after final annealing, for three commonly-used thicknesses are as shown in the table below:

Nominal thickness (mm)	Ranges of specific total loss (W/kg) at			
	50 Hz		60 Hz	
	1.5 T	1.7 T	1.5 T	1.7 T
0.27	0.68 to 0.92	1.00 to 1.40	0.87 to 1.21	1.32 to 1.85
0.30	0.73 to 1.07	1.00 to 1.60	0.97 to 1.41	1.34 to 2.0
0.35	0.80 to 1.23	1.09 to 1.85	1.06 to 1.61	1.42 to 2.45

C22.0.3 Main applications

These materials are used mainly for the manufacture of a.c. magnetic cores in which most of the length of the flux path is linear, as for example in transformer cores.

C23. THIN SILICON STEELS FOR USE AT HIGHER FREQUENCIES

C23.0.1 General

C23.0.1.1 Chemical composition

The basic constituent of these materials is iron. The main alloying element is silicon between 2.0% and 4.0% together with unavoidable impurities and low levels of other elements which may arise from additions necessitated during the manufacturing process.

C23.0.1.2 Basis of sub-classification

The recommended sub-classification is based on the anisotropy and the specific total losses which are a function of thickness, magnetic flux density value and test frequency.

C23.0.1.3 Available forms

The material is normally supplied in the form of coil and sheet.

C23.0.2 Physical characteristics

In addition to the values of specific total losses, a more complete definition of these materials can be based on the following characteristics:

Magnetic: Flux density for different values of the magnetizing field;

Electrical: Surface insulation; resistivity;

Mechanical: Ductility; stacking factor; flatness, edge camber;

Metallurgical state: Annealed and fully recrystallized;

Dimensions: Thickness and width.

Recommended thicknesses and conditions of measurement are as follows:

Type	Thickness (mm)	Magnetic flux density (T)	Frequency (Hz)
Anisotropic (oriented)	0.025	0.2	8 000
	0.050	1.5	400
	0.100	1.5	400
	0.150	1.5	400
	0.200	1.5	400
Isotropic (non-oriented)	0.100	1.0	400
	0.125	1.0	400
	0.150	1.0	400
	0.175	1.0	400
	0.200	1.0	400

The magnetic properties are determined on test pieces which have been annealed in accordance with the recommendations of the manufacturer.

C23.0.3 Main applications

These materials are mainly used in magnetic circuits of transformer and rotating machines operating at frequencies above 100 Hz.

D OTHER STEELS

D1. SOLID MATERIAL

D11. CAST SOLID STEELS

D11.0.1 General

D11.0.1.1 Chemical composition

The basic constituent of these materials is iron containing unavoidable impurities. The main alloying elements are carbon, whose content is lower than 0.3%, and other elements (typically manganese, molybdenum, vanadium and silicon) which may arise from additions necessitated during the manufacturing process to develop the required properties.