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Sintered metal materials — Specifications

Matériaux métalliques frittés — Spécifications

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 5755 was prepared by Technical Committee ISO/TC 119, *Powder metallurgy*, Subcommittee SC 5, *Specifications for powder metallurgical materials (excluding hardmetals)*.

This third edition cancels and replaces the second edition (ISO 5755:2001), which has been technically revised.

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Sintered metal materials — Specifications

1 Scope

This International Standard specifies the requirements for the chemical composition and the mechanical and physical properties of sintered metal materials used for bearings and structural parts.

When selecting powder metallurgical (PM) materials, it should be taken into account that the properties depend not only on the chemical composition and density, but also on the production methods. The properties of sintered materials giving satisfactory service in particular applications may not necessarily be the same as those of wrought or cast materials that might otherwise be used. Therefore, liaison with prospective suppliers is recommended.

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 437, *Steel and cast iron — Determination of total carbon content — Combustion gravimetric method*

ISO 1099, *Metallic materials — Fatigue testing — Axial force-controlled method*

ISO 1143, *Metallic materials — Rotating bar bending fatigue testing*

ISO 2738, *Sintered metal materials, excluding hardmetals — Permeable sintered metal materials — Determination of density, oil content and open porosity*

ISO 2739, *Sintered metal bushings — Determination of radial crushing strength*

ISO 2740, *Sintered metal materials, excluding hardmetals — Tensile test pieces*

ISO 2795, *Plain bearings — Sintered bushes — Dimensions and tolerances*

ISO 3325, *Sintered metal materials, excluding hardmetals — Determination of transverse rupture strength*

ISO 3928, *Sintered metal materials, excluding hardmetals — Fatigue test pieces*

ISO 3954, *Powders for powder metallurgical purposes — Sampling*

ISO 4498, *Sintered metal materials, excluding hardmetals — Determination of apparent hardness and micro-hardness*

ISO 5754, *Sintered metal materials, excluding hardmetals — Unnotched impact test piece*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 7625, *Sintered metal materials, excluding hardmetals — Preparation of samples for chemical analysis for determination of carbon content*

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ISO 14317, *Sintered metal materials, excluding hardmetals — Determination of compressive yield strength*

ASTM E228, *Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push-Rod Dilatometer*

ASTM E1875, *Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Poisson's Ratio by Sonic Resonance*

3 Terms and definitions

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

3.1
tensile strength
R_m
ability of a test specimen to resist fracture when a pulling force is applied in a direction parallel to its longitudinal axis – expressed in MPa

NOTE It is equal to the maximum load divided by the original cross-sectional area.

3.2
tensile yield strength
$R_{p0,2}$
load at which the material exhibits a 0,2 % offset from proportionality on a stress-strain curve in tension, divided by the original cross-sectional area – expressed in MPa

3.3
Young's modulus
E
ratio of normal stress to corresponding strain for tensile or compressive stresses below the proportional limit of the material – expressed in GPa

3.4
Poisson's ratio
v
absolute value of the ratio of transverse strain to the corresponding axial strain, resulting from uniformally distributed axial stress below the proportional limit of the material

3.5
impact energy
measurement of the energy absorbed when fracturing a specimen with a single blow – measured in Joules (J)

3.6
compressive yield strength
stress at which a material exhibits a specified permanent set – expressed in MPa

3.7
transverse rupture strength
stress, calculated from the bending strength formula, required to break a specimen of a given dimension – expressed in MPa

3.8
fatigue strength
maximum alternating stress that can be sustained for a specific number of cycles without failure, the stress being reversed with each cycle unless otherwise stated – expressed in MPa

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3.9
radial crushing strength
radial stress required to fracture a hollow cylindrical part of specified dimensions – expressed in MPa

3.10
density
mass per unit volume of the material – expressed in g/cm^3

3.11
apparent hardness
resistance of a powder metallurgical (PM) material to indentation, tested under specified conditions; for PM materials, it is a function of the density of the material

3.12
open porosity
oil content after full impregnation, divided by the volume of the test piece, and multiplied by 100 – expressed as a volume percentage

3.13
coefficient of linear expansion
change in length per unit length per degree change in temperature – expressed in 10^{-6} K^{-1}

4 Sampling

Sampling of powders to produce standard test pieces shall be carried out in accordance with ISO 3954.

5 Test methods for normative properties

5.1 General

The following test methods shall be used to determine the normative properties given in Tables 1 to 18.

5.2 Chemical analysis

The chemical composition table for each material lists the principal elements by minimum and maximum mass percentage before any additional process, such as oil impregnation, resin impregnation or steam treatment, has taken place. “Other elements” may include minor amounts of elements added for specific purposes and is reported as a maximum percentage.

Whenever possible, and always in cases of dispute, the methods of chemical analysis shall be those specified in the relevant International Standards. If no International Standard is available, the method may be agreed upon and specified at the time of enquiry and order.

Samples for the determination of total carbon content shall be prepared in accordance with ISO 7625. Determination of the total carbon content shall be in accordance with ISO 437.

5.3 Open porosity

The open porosity shall be determined in accordance with ISO 2738.

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5.4 Mechanical properties

5.4.1 General

The as-sintered mechanical properties given in Tables 1 to 18 were determined on pressed and sintered test pieces with a mean chemical composition. The heat-treated mechanical properties given in Tables 1 to 18 were determined on test bars which were either pressed and sintered or machined from pressed and sintered blanks. They are intended as a guide to the initial selection of materials (see also Clause 1). They may also be used as a basis for specifying any special tests that may be indicated on the drawing.

The mechanical properties shall neither be calculated from hardness values nor be determined on tensile test pieces taken from a component and used for verifying the values given in Tables 1 to 18. If the customer requires that a specified level of mechanical properties be obtained by tests on the component, these shall be agreed with the supplier and shall be stated on the drawing and/or any technical documentation of the customer referred to on the drawing.

5.4.2 Tensile properties

The ultimate tensile strength and the yield strength shall be determined in accordance with ISO 2740 and, ISO 6892-1. For heat-treated materials, tensile strength and yield strength are approximately equal and in this case, tensile strength is specified.

The normative yield strengths (as-sintered condition) and ultimate tensile strengths (heat-treated condition) are shown as minimum values. These strengths may be used in designing PM part applications. To select a material which is optimum in both properties and cost-effectiveness, it is essential that the part application be discussed with the PM parts manufacturer.

The minimum values were developed from tensile specimens prepared specifically for evaluating PM materials.

Tensile specimens machined from commercial parts may differ from those obtained from prepared tensile specimens. To evaluate the part strength, it is recommended that static or dynamic proof-testing be agreed between the purchaser and the manufacturer and carried out on the first production lot of parts. The results of testing to failure can be used statistically to determine a minimum breaking force for future production lots.

Acceptable strength can also be demonstrated by processing tensile specimens prepared specifically for evaluating PM materials manufactured from the same batch of powder as the production parts and processed with them.

As indicated above, the testing of test bars machined from the PM component is the least desirable method for demonstrating minimum properties.

For heat-treated properties, the test bars were quench-hardened and tempered to increase the strength, hardness and wear resistance. Tempering is essential to develop the properties given in this International Standard. Heat-treat equipment that utilizes a gas atmosphere or vacuum is recommended. The use of liquid salts is not recommended due to entrapment of the salts in the porosity causing “salt bleed-out” and “internal corrosion”. Some materials may be heat-treated directly after the sintering process by controlling the cooling rate within the sintering furnace. This process is usually known as “sinter hardening”. Materials processed by this route also require tempering to develop their optimum strengths.

5.4.3 Radial crushing strength

The radial crushing strength shall be determined in accordance with ISO 2739. The wall thicknesses of test pieces to be used shall be in the range covered by ISO 2795. For test pieces outside this range, the specified radial crushing strength values are different and shall be agreed between the customer and the supplier.

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6 Test methods for informative properties

6.1 General

Typical values are given for each material; these include tensile and yield strengths. These typical values are given for general guidance only. They should not be used as minimum values.

These typical properties should be achievable through normal manufacturing processing. Again, any specific tests on components should be discussed and agreed between the purchaser and the manufacturer.

6.2 Density

Density is expressed in grams per cubic centimetre (g/cm^3). The density shall be determined in accordance with ISO 2738. Density is normally determined after the removal of any oils or non-metallic materials from the porosity and is known as the “dry density”. The “wet density” is sometimes reported on production bearings or parts, this is the mass per unit volume, including any oil or non-metallic material that has impregnated the component.

6.3 Tensile strength

The tensile strength shall be determined in accordance with ISO 2740 and ISO 6892-1.

6.4 Tensile yield strength

The tensile yield strength shall be determined in accordance with ISO 2740 and ISO 6892-1.

6.5 Elongation

Elongation (plastic) shall be determined in accordance with ISO 6892-1. It is expressed as a percentage of the original gauge length (usually 25 mm), and is determined by on measuring the increase in gauge length after the fracture, providing the fracture takes place within the gauge length. Elongation can also be measured with a break-away extensometer on a tensile specimen. The recorded stress/strain curve displays total elongation (elastic and plastic). The elastic strain must be subtracted from the total elongation to give the plastic elongation (this can sometimes be provided with the test machine’s software).

6.6 Young’s modulus

Young’s modulus shall be determined in accordance with ASTM E1875. Data for the elastic constants in this International Standard were generated from resonant frequency testing. An equation relating the three elastic constants is:

$$v = \left(E/2G\right) - 1$$

where

- v is Poisson’s ratio;
- E is Young’s modulus;
- G is the shear modulus.

6.7 Poisson’s ratio

Poisson’s ratio shall be determined in accordance with ASTM E1875.

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6.8 Impact energy

The impact energy shall be determined in accordance with ISO 5754. The data in this International Standard were obtained using an unnotched Charpy specimen.

6.9 Compressive yield strength

The compressive yield strength shall be determined in accordance with ISO 14317. For certain heat-treated materials listed in the tables, the hardenability is not sufficient to completely through-harden the 9,00 mm diameter test specimen. Due to variation in hardenability among the heat-treated steels listed in the tables, the compressive yield strength data are appropriate only for 9,00 mm sections. Typically, smaller cross-sections have higher compressive yield strengths and larger sections have somewhat lower strengths due to the hardenability response. Since the cross-section of the tensile yield test specimen is smaller than the compressive yield specimen, a direct correspondence between tensile and compressive yield strength data is not possible.

6.10 Transverse rupture strength

The transverse rupture strength shall be determined in accordance with ISO 3325.

The strength formula in ISO 3325 is strictly valid only for non-ductile materials; nevertheless, it is widely used for materials that bend at fracture, and is useful for establishing comparative strengths. Data for such materials are included as typical properties in ISO 3325.

6.11 Fatigue strength

6.11.1 General

The number of cycles survived should be stated with each strength listed.

For PM ferrous materials, like wrought ferrous materials, fatigue strengths of 10^7 cycles in duration using unnotched specimens are considered to be sustainable indefinitely and are therefore considered to be fatigue limits (also termed endurance limits). By contrast, non-ferrous PM materials do not have 10^7 cycle maximum fatigue strengths sustainable for indefinite times and these stress limits therefore simply remain as the fatigue strength at 10^7 cycles.

The fatigue limits in this International Standard were generated through statistical analysis of the test data. Due to the limited number of data points available for the analysis, these fatigue strengths were determined as the 90 % survival stress, i.e. the fatigue stress at which 90 % of the test specimens survived 10^7 cycles.

There are three methods of stressing the test specimens and each gives different fatigue strengths. These are described in 6.11.2 to 6.11.4.

6.11.2 Rotating bending fatigue strength

This test method uses a machined, round, smooth test specimen (in accordance with ISO 3928), with an R. R. Moore testing machine. Testing is conducted in accordance with ISO 1143. The specimen is held at one end and rotated while it is stressed at the other end. The surface of the test bar is the most highly stressed area and the centre line has a neutral stress. This test method gives the highest fatigue strength.

6.11.3 Plane-bending fatigue strength

This method used for plane-bending fatigue uses a standard sintered fatigue test bar (in accordance with ISO 3928) that is subjected to an alternating stress. This test method gives a slightly lower fatigue strength than the rotating bending fatigue test, as more of the cross-sectional area is subjected to the stress. Evaluation of fatigue strength is done according to the staircase method described in MPIF Standard 56.

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6.11.4 Axial fatigue strength

This method uses either a machined, round or standard sintered fatigue test bar (in accordance with ISO 3928) that is tested in a test machine by clamping both ends and subjecting the test bar to alternating stresses where $R = -1$. Testing is conducted in accordance with ISO 1099. As the whole of the cross-section is stressed, this test method gives the lowest fatigue strength.

6.12 Apparent hardness

The apparent hardness shall be determined in accordance with ISO 4498. The hardness value of a PM part when using a conventional indentation hardness tester is referred to as “apparent hardness” because it represents a combination of matrix hardness plus the effect of porosity. Apparent hardness measures the resistance to indentation.

Because of possible density variations in a finished PM part, the location of critical apparent hardness measurements should be specified on the engineering drawing of the part. As surface pore closure can affect the apparent hardness, the surface condition should also be specified.

6.13 Coefficient of linear expansion

The coefficient of linear expansion shall be determined in accordance with ASTM E228.

7 Specifications

The chemical composition and mechanical properties are given in Tables 1 to 18.

The liquid lubricant content of materials for bearings, impregnated with liquid lubricant, shall be not less than 90 % of the measured open porosity.

8 Designations

Designations shall be in accordance with Annex A.

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Table 1 — Non-ferrous materials for bearings: bronze and bronze with graphite

	Grade[a]	Normative values						Informative values	
		Chemical composition				Open porosity min.	Radial crushing strength min.	Density (dry)	Coefficient of linear expansion
		Graphite	Sn	Cu	Total other elements max.				
		%	%	%	%	p %	K MPa	ρ g/cm^3	10^{-6} K^{-1}
Bronze	-C-T10-K110		8,5 to 11,0	Balance	2	27	110	6,1	18
	-C-T10-K140		8,5 to 11,0	Balance	2	22	140	6,6	18
	-C-T10-K180		8,5 to 11,0	Balance	2	15	180	7,0	18
Bronze with graphite	-C-T10G-K90	0,5 to 2,0	8,5 to 11,0	Balance	2	27	90	5,9	18
	-C-T10G-K110[b]	0,5 to 2,0	8,5 to 11,0	Balance	2	25	110	6,0	18
	-C-T10G-K120	0,5 to 2,0	8,5 to 11,0	Balance	2	22	120	6,4	18
	-C-T10G-K170[b]	0,5 to 2,0	8,5 to 11,0	Balance	2	19	170	6,5	18
	-C-T10G-K160	0,5 to 2,0	8,5 to 11,0	Balance	2	17	160	6,8	18
	-C-T10G-K115	3 to 5	8,5 to 11,0	Balance	2	11	115	6,8	19

[a] All materials can be oil-impregnated.

[b] These materials have a higher strength than would be expected from the porosity listed, which may require different sintering parameters.

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Table 2 — Ferrous materials for bearings: iron, iron-copper, iron-bronze and iron-carbon graphite

	Grade[a]	Normative values								Informative values	
		Chemical composition						Open porosity min.	Radial crushing strength	Density (dry)	Coefficient of linear expansion
		C combined[b]	Cu	Sn	Graphite	Fe	Total other elements max.				
		%	%	%	%	%	%	p %	K MPa	ρ g/cm^3	10^{-6} K^{-1}
Iron	-F-00-K170	<0,3				Balance	2	22	>170	5,8	12
	-F-00-K220	<0,3				Balance	2	17	>220	6,2	12
Iron copper	-F-00C2-K200	<0,3	1 to 4			Balance	2	22	>200	5,8	12
	-F-00C2-K250	<0,3	1 to 4			Balance	2	17	>250	6,2	12
	-F-03C22-K150	<0,5	18 to 25			Balance	2	18	>150	6,4	13
	-F-03C22G-K150	<0,5	18 to 25		0,3 to 1,0	Balance	2	18	>150	6,4	13
	-F-03C22G-K200[d]	<0,5	18 to 25		1,0 to 3,0	Balance	2	18	>200	6,4	13
	-F-03C25T-K120	<0,5	20 to 30	1,0 to 3,0		Balance	2	17	120 to 250	6,4	13
Iron bronze[c]	-F-03C36T-K90	<0,5	34 to 38	3,5 to 4,5	0,3 to 1,0	Balance	2	24	90 to 265	5,8	14
	-F-03C36T-K120	<0,5	34 to 38	3,5 to 4,5	0,3 to 1,0	Balance	2	19	120 to 345	6,2	14
	-F-03C45T-K70	<0,5	43 to 47	4,5 to 5,5	<1,0	Balance	2	24	70 to 245	5,6	14
	-F-03C45T-K100	<0,5	43 to 47	4,5 to 5,5	<1,0	Balance	2	19	100 to 310	6,0	14
Iron-carbon graphite[c]	-F-03G3-K70	<0,5			2,0 to 3,5	Balance	2	20	70 to 175	5,6	12
	-F-03G3-K80	<0,5			2,0 to 3,5	Balance	2	13	80 to 210	6,0	12

a All materials can be oil-impregnated.

b On the basis of iron phase only.

c The range of values given for radial crushing strength (K) indicates the necessity to maintain a balance between combined carbon and free graphite.

d This material has a higher strength than would be expected from the porosity listed, which may require different sintering parameters.

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Table 3 — Ferrous materials for structural parts: iron and carbon steel — As sintered

	Grade	Normative values					Informative values											
		Chemical composition				Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[a]	Apparent hardness	
		C combined	Cu	Fe	Total other elements max.													
		%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV5	Rockwell
Iron	-F-00-100	< 0,3	-	Balance	2	100	6,7	170	120	3	120	0,25	8	120	340	65	60	60 HRF
	-F-00-120	< 0,3	-	Balance	2	120	7,0	210	150	4	140	0,27	24	125	500	80	75	70 HRF
	-F-00-140	< 0,3	-	Balance	2	140	7,3	260	170	7	160	0,28	47	130	660	100	85	80 HRF
Carbon steel	-F-05-100	0,3 to 0,6	-	Balance	2	100	6,1	170	120	<1	105	0,25	4	125	330	60	70	25 HRB
	-F-05-140	0,3 to 0,6	-	Balance	2	140	6,6	220	160	1	115	0,25	5	160	440	80	90	40 HRB
	-F-05-170	0,3 to 0,6	-	Balance	2	170	7,0	275	200	2	140	0,27	8	200	550	105	120	60 HRB
Carbon steel	-F-08-170	0,6 to 0,9	-	Balance	2	170	6,2	240	210	<1	110	0,25	4	210	420	100	110	50 HRB
	-F-08-210	0,6 to 0,9	-	Balance	2	210	6,6	290	240	1	115	0,25	5	210	510	120	120	60 HRB
	-F-08-240	0,6 to 0,9	-	Balance	2	240	7,0	390	260	1	140	0,27	7	250	690	170	140	70 HRB

These materials may be supplied with additives to improve machinability.

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

[a] Machined test pieces according to ISO 3928.

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Table 4 — Ferrous materials for structural parts: carbon steel — Heat-treated

Grade	Normative values					Informative values										
	Chemical composition				Ultimate tensile strength min.	Density	Tensile strength[c]	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[d]	Apparent hardness	
	C combined	Cu	Fe	Total other elements max.												
	%	%	%	%	R_m MPa	ρ g/cm^3	R_m MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV10	Rockwell
-F-05-340H[a]	0,3 to 0,6	-	Balance	2	340	6,6	410	< 1	115	0,25	4	300	720	160	280	20 HRC
-F-05-410H[a]	0,3 to 0,6	-	Balance	2	410	6,8	480	< 1	130	0,27	5	360	830	190	290	22 HRC
-F-05-480H[a]	0,3 to 0,6	-	Balance	2	480	7,0	550	< 1	140	0,27	5	420	970	220	300	25 HRC
-F-08-450H[b]	0,6 to 0,9	-	Balance	2	450	6,6	520	< 1	115	0,25	5	550	790	210	320	28 HRC
-F-08-500H[b]	0,6 to 0,9	-	Balance	2	500	6,8	570	< 1	130	0,27	6	600	860	230	345	31 HRC
-F-08-550H[b]	0,6 to 0,9	-	Balance	2	550	7,0	620	< 1	140	0,27	7	655	950	260	360	33 HRC

Heat-treated tensile properties were derived from machined test bars according to ISO 2740.

a Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered at 180 °C for 1 h.

b Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,8 % carbon potential, oil-quenched and tempered at 180 °C for 1 h.

c Tensile yield and ultimate tensile strength are approximately the same for heat-treated materials.

d Machined test pieces according to ISO 3928.

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Table 5 — Ferrous materials for structural parts: copper steel and copper-carbon steel — As sintered

Grade		Normative values: Chemical composition: C combined	Normative values: Chemical composition: Cu	Normative values: Chemical composition: Fe	Normative values: Chemical composition: Total other elements max.	Normative values: Tensile yield strength min.	Informative values: Density	Informative values: Tensile strength	Informative values: Tensile yield strength	Informative values: Elongation	Informative values: Young's modulus	Informative values: Poisson's ratio	Informative values: Unnotched Charpy impact	Informative values: Compressive yield strength	Informative values: Transverse rupture strength	Informative values: Rotating fatigue limit 90 % survival[a]	Informative values: Bending fatigue limit 90 % survival[b]	Informative values: Axial fatigue limit 90 % survival[c]	Informative values: Apparent hardness	
		%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	MPa	HV5	Rockwell
Copper steel	-F-00C2-110	<0,3	1,3 to 3,0	Balance	2	110	6,2	180	150	1,5	110	0,25	6	130	340	70			60	16 HRB
	-F-00C2-140	<0,3	1,3 to 3,0	Balance	2	140	6,6	210	180	2	115	0,25	7	160	390	80			70	26 HRB
	-F-00C2-175	<0,3	1,3 to 3,0	Balance	2	175	7,0	235	205	3	140	0,27	8	185	445	89			90	39 HRB
Copper-carbon steels	-F-05C2-230	0,3 to 0,6	1,3 to 3,0	Balance	2	230	6,2	270	270	<1	110	0,25	3	270	480	95			110	44 HRB
	-F-05C2-270	0,3 to 0,6	1,3 to 3,0	Balance	2	270	6,6	325	300	<1	115	0,25	7	305	620	130			115	57 HRB
	-F-05C2-300	0,3 to 0,6	1,3 to 3,0	Balance	2	300	7,0	390	330	<1	140	0,27	10	330	760	190		150	150	68 HRB
	-F-08C2-270	0,6 to 0,9	1,3 to 3,0	Balance	2	270	6,2	320	300	<1	110	0,25	3	300	580	110		90	115	58 HRB
	-F-08C2-350	0,6 to 0,9	1,3 to 3,0	Balance	2	350	6,6	390	360	<1	115	0,25	7	330	800	150		120	140	70 HRB
	-F-08C2-390	0,6 to 0,9	1,3 to 3,0	Balance	2	390	7,0	480	420	<1	140	0,27	8	360	980	200		170	165	78 HRB
	-F-08C2-410	0,6 to 0,9	1,3 to 3,0	Balance	2	410	7,2	520	450	<1	155	0,28	9	380	1070	230		190	185	84 HRB

These materials may be supplied with additives to improve machinability.

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

a Machined test pieces according to ISO 3928.

b As-sintered test pieces (sintered surfaces) according to ISO 3928.

c Machined test pieces according to ISO 3928.

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Table 6 — Ferrous materials for structural parts: copper-carbon steel — Heat-treated

Grade	Normative values					Informative values										
	Chemical composition				Ultimate tensile strength min.	Density	Tensile strength[c]	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[d]	Apparent hardness	
	C combined	Cu	Fe	Total other elements max.												
	%	%	%	%	R_m MPa	g/cm^3	R_m MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV10	Rockwell
-F-05C2-410H[a]	0,3 to 0,6	1,3 to 3,0	Balance	2	410	6,2	480	<1	110	0,25	3	390	660	190	270	19 HRC
-F-05C2-500H[a]	0,3 to 0,6	1,3 to 3,0	Balance	2	500	6,6	580	<1	115	0,25	5	520	800	220	310	27 HRC
-F-05C2-620H[a]	0,3 to 0,6	1,3 to 3,0	Balance	2	620	7,0	690	<1	140	0,27	7	660	930	260	390	36 HRC
-F-08C2-360H[b]	0,6 to 0,9	1,3 to 3,0	Balance	2	360	6,2	470	<1	110	0,25	4	430	690	180	290	22 HRC
-F-08C2-500H[b]	0,6 to 0,9	1,3 to 3,0	Balance	2	500	6,6	570	<1	115	0,25	6	560	830	230	360	33 HRC
-F-08C2-620H[b]	0,6 to 0,9	1,3 to 3,0	Balance	2	620	7,0	690	<1	140	0,27	6	690	1 000	270	430	40 HRC
-F-08C2-670H[b]	0,6 to 0,9	1,3 to 3,0	Balance	2	670	7,2	750	<1	155	0,28	7	750	1 070	290	470	44 HRC

Heat-treated tensile properties were derived from machined test bars according to ISO 2740.

[a] Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered at 180 °C for 1 h.

[b] Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,8 % carbon potential, oil-quenched and tempered at 180 °C for 1 h.

[c] Tensile yield and ultimate tensile strength are approximately the same for heat-treated materials.

[d] Machined test pieces according to ISO 3928.

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Table 7 — Ferrous materials for structural parts: phosphorus steels — As sintered

Grade		Normative values						Informative values										
		Chemical composition					Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Transverse rupture strength	Bending fatigue limit 90 % survival [b]	Apparent hardness	
		C combined	P	Cu	Fe	Total other elements max.												
		%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	MPa	MPa	HV5	Rockwell
Phosphorus steel[a]	-F-00P05-180	< 0,1	0,40 to 0,50	-	Balance	2	180	6,6	300	210	4	115	0,25	18	600	95	70	40 HRB
	-F-00P05-210	< 0,1	0,40 to 0,50	-	Balance	2	210	7,0	400	240	9	140	0,27	30	900	125	120	60 HRB
Phosphorus -carbon steel	-F-05P05-270	0,3 to 0,6	0,40 to 0,50	-	Balance	2	270	6,6	400	305	3	115	0,25	9	700	125	130	65 HRB
	-F-05P05-320	0,3 to 0,6	0,40 to 0,50	-	Balance	2	320	7,0	480	365	5	140	0,27	15	1 000	160	150	72 HRB
Copper-phosphorus steel	-F-00C2P-260	< 0,3	0,40 to 0,50	1,5 to 2,5	Balance	2	260	6,6	400	300	3	115	0,25			115	120	60 HRB
	-F-00C2P-300	< 0,3	0,40 to 0,50	1,5 to 2,5	Balance	2	300	7,0	500	340	6	140	0,27			145	140	69 HRB
Copper-phosphorus -carbon steel	-F-05C2P-320	0,3 to 0,6	0,40 to 0,50	1,5 to 2,5	Balance	2	320	6,6	450	360	2	115	0,25		820	135	140	69 HRB
	-F-05C2P-380	0,3 to 0,6	0,40 to 0,50	1,5 to 2,5	Balance	2	380	7,0	550	400	3	140	0,27		1 120	165	160	74 HRB

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

a Consultation with the supplier is recommended before these materials are used in magnetic applications. Some soft magnetic PM materials are standardized in IEC 60404-8-9.

b As-sintered test pieces (sintered surfaces) according to ISO 3928.

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Table 8 — Ferrous materials for structural parts: nickel steels — As sintered

Grade	Normative values						Informative values											
	Chemical composition					Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[a]	Apparent hardness	
	C combined	Ni	Cu	Fe	Total other elements max.													
	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV5	Rockwell
-F-05N2-140	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	140	6,6	280	170	1,5	115	0,25	8	170	450	100	80	44 HRB
-F-05N2-180	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	180	7,0	360	220	2,5	140	0,27	20	210	740	130	130	62 HRB
-F-05N2-210	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	210	7,2	410	240	4,0	155	0,28	28	240	860	150	145	69 HRB
-F-05N2-240	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	240	7,4	480	280	5,5	170	0,28	46	280	1030	180	170	78 HRB
-F-08N2-220	0,6 to 0,9	1,5 to 2,5	0,0 to 2,5	Balance	2	220	6,8	350	260	1,5	130	0,27	9	260	660	120	145	68 HRB
-F-08N2-260	0,6 to 0,9	1,5 to 2,5	0,0 to 2,5	Balance	2	260	7,0	430	300	1,5	140	0,27	13	300	800	150	160	74 HRB
-F-08N2-300	0,6 to 0,9	1,5 to 2,5	0,0 to 2,5	Balance	2	300	7,2	515	325	2,2	155	0,28	18	325	985	180	175	80 HRB
-F-05N4-180	0,3 to 0,6	3,5 to 4,5	0,0 to 2,0	Balance	2	180	6,6	285	220	1,0	115	0,25	8	240	500	110	105	53 HRB
-F-05N4-240	0,3 to 0,6	3,5 to 4,5	0,0 to 2,0	Balance	2	240	7,0	410	280	3,0	140	0,27	20	280	830	150	145	71 HRB
-F-05N4-310	0,3 to 0,6	3,5 to 4,5	0,0 to 2,0	Balance	2	310	7,4	620	340	4,5	170	0,28	45	310	1210	220	185	84 HRB
-F-08N4-300	0,6 to 0,9	3,5 to 4,5	0,0 to 2,0	Balance	2	300	6,8	420	320	1,0	130	0,27	9	320	720	150	160	75 HRB
-F-08N4-330	0,6 to 0,9	3,5 to 4,5	0,0 to 2,0	Balance	2	330	7,0	480	360	1,0	140	0,27	11	360	850	170	175	80 HRB
-F-08N4-380	0,6 to 0,9	3,5 to 4,5	0,0 to 2,0	Balance	2	380	7,2	550	410	1,0	155	0,28	15	410	1030	190	205	87 HRB

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

[a] Machined test pieces according to ISO 3928.

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Table 9 — Ferrous materials for structural parts: nickel steels — Heat-treated

Grade	Normative values						Informative values										
	Chemical composition					Ultimate tensile strength min.	Density	Tensile strength[c]	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[d]	Apparent hardness	
	C combined	NI	Cu	Fe	Total other elements max.												
	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV10	Rockwell
-F-05N2-550H[a]	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	550	6,6	620	<1	115	0,25	5	410	830	180	290	23 HRC
-F-05N2-800H[a]	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	800	7,0	900	<1	140	0,27	7	600	1 200	260	350	31 HRC
-F-05N2-1070H[a]	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	1 070	7,2	1 100	<1	155	0,28	9	830	1 480	320	390	36 HRC
-F-05N2-1240H[a]	0,3 to 0,6	1,5 to 2,5	0,0 to 2,5	Balance	2	1 240	7,4	1 280	<1	170	0,28	13	970	1 720	370	430	40 HRC
-F-08N2-600H[b]	0,6 to 0,9	1,5 to 2,5	0,0 to 2,5	Balance	2	600	6,7	620	<1	120	0,25	5	680	830	200	310	26 HRC
-F-08N2-900H[b]	0,6 to 0,9	1,5 to 2,5	0,0 to 2,5	Balance	2	900	7,0	1 000	<1	140	0,27	7	940	1 280	320	380	35 HRC
-F-08N2-1070H[b]	0,6 to 0,9	1,5 to 2,5	0,0 to 2,5	Balance	2	1 070	7,2	1 170	<1	155	0,28	9	1 120	1 520	370	420	39 HRC
-F-05N4-600H[a]	0,3 to 0,6	3,5 to 4,5	0,0 to 2,0	Balance	2	600	6,6	640	<1	115	0,25	6	510	860	190	270	21 HRC
-F-05N4-900H[a]	0,3 to 0,6	3,5 to 4,5	0,0 to 2,0	Balance	2	900	7,0	930	<1	140	0,27	9	710	1 380	290	350	31 HRC
-F-05N4-1240H[a]	0,3 to 0,6	3,5 to 4,5	0,0 to 2,0	Balance	2	1 240	7,4	1 280	<1	170	0,28	18	910	1 930	390	430	40 HRC

Heat-treated tensile properties were derived from machined test bars according to ISO 2740.

a Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered at 260 °C for 1 h.

b Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,8 % carbon potential, oil-quenched and tempered at 260 °C for 1 h.

c Tensile yield and ultimate tensile strength are approximately the same for heat-treated materials.

d Machined test pieces according to ISO 3928.

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Table 10 — Ferrous materials for structural parts: diffusion-alloyed nickel-copper-molybdenum steels — As sintered

Grade[a]	Normative values							Informative values												
	Chemical composition						Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[b]	Bending fatigue limit 90 % survival[c]	Apparent hardness	
	C combined	Ni	Cu	Mo	Fe	Total other elements max.														
	%	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	HV5	Rockwell
-FD-05N2C-360	0,3 to 0,6	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	360	6,9	540	390	2	135	0,27	14	350	1 040	190	170	155	74 HRB
-FD-05N2C-400	0,3 to 0,6	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	400	7,1	590	420	3	150	0,27	22	380	1 200	220	195	180	81 HRB
-FD-05N2C-440	0,3 to 0,6	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	440	7,4	680	460	4	170	0,28	38	430	1 450	260	220	210	86 HRB
-FD-08N2C-350	0.6 to 0.9	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	350	6,8	500	410	<1	130	0,27	10	410	980	195	190	175	80 HRB
-FD-08N2C-390	0.6 to 0.9	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	390	7,0	580	450	1	140	0,27	14	450	1 160	240	210	190	84 HRB
-FD-08N2C-430	0.6 to 0.9	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	430	7,2	680	490	1	155	0,28	20	490	1 300	300	230	215	87 HRB
-FD-05N4C-400	0,3 to 0,6	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	400	6,9	650	445	1	135	0,27	21	410	1 220		205	170	79 HRB
-FD-05N4C-420	0,3 to 0,6	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	420	7,1	750	465	2	150	0,27	28	440	1 380		215	200	85 HRB
-FD-05N4C-450	0,3 to 0,6	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	450	7,4	875	485	3	170	0,28	39	510	1 630	290	235	230	89 HRB
-FD-08N4C-350	0.6 to 0.9	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	360	6,8	540	410	1	130	0,27	14	450	1 000		240	205	86 HRB
-FD-08N4C-390	0.6 to 0.9	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	390	7,0	650	440	1	140	0,27	19	480	1 190		255	220	88 HRB
-FD-08N4C-430	0.6 to 0.9	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	410	7,2	760	460	1,5	155	0,28	24	500	1 380		270	235	90 HRB

a These materials are produced from diffusion-alloyed powders with the addition of elemental graphite.

b Machined test pieces according to ISO 3928.

c As-sintered test pieces (sintered surfaces) according to ISO 3928.

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Table 11 — Ferrous materials for structural parts: diffusion-alloyed nickel-copper-molybdenum steels — Heat-treated

Grade[a]	Normative values							Informative values										
	Chemical composition						Ultimate tensile strength min.	Density	Tensile strength[c]	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[d]	Apparent hardness	
	C combined	Ni	Cu	Mo	Fe	Total other elements max.												
	%	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV10	Rockwell
-FD-05N2C-700H[b]	0,3 to 0,6	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	700	6,8	770	<1	130	0,27	8	950	1 150	310	340	30 HRC
-FD-05N2C-950H[b]	0,3 to 0,6	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	950	7,1	1 020	<1	150	0,27	11	1 170	1 420	430	400	37 HRC
-FD-05N2C-1100H[b]	0,3 to 0,6	1,5 to 2,0	1,3 to 1,7	0,4 to 0,6	Balance	2	1 100	7,4	1 170	<1	170	0,28	15	1 380	1 650	520	480	45 HRC
-FD-05N4C-725H[b]	0,3 to 0,6	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	725	6,8	780	<1	130	0,27	8	890	1 130		320	31 HRC
-FD-05N4C-930H[b]	0,3 to 0,6	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	930	7,1	1 000	<1	150	0,27	10	1 060	1 420		390	36 HRC
-FD-05N4C-1100H[b]	0,3 to 0,6	3,6 to 4,4	1,3 to 1,7	0,4 to 0,6	Balance	2	1 100	7,4	1 170	<1	170	0,28	15	1 240	1 650		460	43 HRC

Heat-treated tensile properties were derived from machined test bars according to ISO 2740.

a These materials are produced from diffusion-alloyed powders with the addition of elemental graphite.

b Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered at 180 °C for 1 h.

c Tensile yield and ultimate tensile strength are approximately the same for heat-treated materials.

d Machined test pieces according to ISO 3928.

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Table 12 — Ferrous materials for structural parts: pre-alloyed steels — As sintered

Grade[a]	Normative values								Informative values												
	Chemical composition							Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[g]	Bending fatigue limit 90 % survival[h]	Apparent hardness	
	C combined	Ni	Mo	Cr	Mn	Fe	Total other elements max.														
	%	%	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm³	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	HV5	Rockwell
-FL-05M1N-240[b]	0,4 to 0,7	0,35 to 0,55	0,50 to 0,85		0,20 to 0,40	Balance	2	240	6,8	360	290	1	130	0,27	8	290	690	140		120	60 HRB
-FL-05M1N-290[b]	0,4 to 0,7	0,35 to 0,55	0,50 to 0,85		0,20 to 0,40	Balance	2	290	7,0	420	330	1	140	0,27	13	330	810	200		140	67 HRB
-FL-05M1N-325[b]	0,4 to 0,7	0,35 to 0,55	0,50 to 0,85		0,20 to 0,40	Balance	2	325	7,2	480	380	1,5	155	0,28	19	375	940	250		155	72 HRB
-FL-05M1-260[c]	0,4 to 0,7		0,75 to 0,95		0,05 to 0,30	Balance	2	260	6,8	380	305	1	130	0,27	11	290	770	165	175	130	63 HRB
-FL-05M1-295[c]	0,4 to 0,7		0,75 to 0,95		0,05 to 0,30	Balance	2	295	7,0	430	340	1	140	0,27	18	335	910	205	205	150	70 HRB
-FL-05M1-325[c]	0,4 to 0,7		0,75 to 0,95		0,05 to 0,30	Balance	2	325	7,2	480	380	1,5	155	0,28	26	375	1050	250	235	160	76 HRB
-FL-05N2M-250[d]	0,4 to 0,7	1,75 to 2,00	0,45 to 0,60		0,05 to 0,30	Balance	2	250	6,8	370	295	1	130	0,27	10	295	720	150	150	125	61 HRB
-FL-05N2M-285[d]	0,4 to 0,7	1,75 to 2,00	0,45 to 0,60		0,05 to 0,30	Balance	2	285	7,0	410	330	1	140	0,27	17	330	865	200	185	140	66 HRB
-FL-05N2M-320[d]	0,4 to 0,7	1,75 to 2,00	0,45 to 0,60		0,05 to 0,30	Balance	2	320	7,2	470	370	1,5	155	0,28	24	370	1010	235	215	155	72 HRB
-FL-07Cr2M-485[e]	0,6 to 0,8		0,15 to 0,30	1,3 to 1,7	0,05 to 0,30	Balance	2	485	6,8	690	515	1	130	0,27	14	465	1205	200	200	195	84 HRB
-FL-07Cr2M-535[e]	0,6 to 0,8		0,15 to 0,30	1,3 to 1,7	0,05 to 0,30	Balance	2	535	7,0	795	575	1,5	140	0,27	18	555	1415	230	230	220	88 HRB

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Table 12 (*continued*)

Grade[a]	Normative values								Informative values												
	Chemical composition							Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[g]	Bending fatigue limit 90 % survival[h]	Apparent hardness	
	C combined	Ni	Mo	Cr	Mn	Fe	Total other elements max.														
	%	%	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm³	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	HV5	Rockwell
-FL-07Cr2M-570[e]	0,6 to 0,8		0,15 to 0,30	1,3 to 1,7	0,05 to 0,30	Balance	2	570	7,2	880	630	2,5	155	0,28	22	625	1 640	260	250	240	90 HRB
-FL-05Cr3M-570[f]	0,4 to 0,6		0,40 to 0,60	2,7 to 3,3	0,05 to 0,30	Balance	2	570	6,8	810	640	< 1	130	0,27	12	560	1 365	205		235	90 HRB
-FL-05Cr3M-670[f]	0,4 to 0,6		0,40 to 0,60	2,7 to 3,3	0,05 to 0,30	Balance	2	670	7,0	915	740	< 1	140	0,27	14	645	1 520	240		260	92 HRB
-FL-05Cr3M-775[f]	0,4 to 0,6		0,40 to 0,60	2,7 to 3,3	0,05 to 0,30	Balance	2	775	7,2	1040	845	< 1	155	0,28	16	740	1 655	275		320	28 HRC

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

a These materials are produced from pre-alloyed powders with the addition of elemental graphite.

b Pre-alloy base powder with a nominal composition 0,45 % Ni, 0,7 % Mo, 0,35 % Mn, balance Fe.

c Pre-alloy base powder with a nominal composition 0,85 % Mo, 0,2 % Mn, balance Fe.

d Pre-alloy base powder with a nominal composition 1,8 % Ni, 0,5 % Mo, 0,2 % Mn, balance Fe.

e Pre-alloy base powder with a nominal composition 1,5 % Cr, 0,2 % Mo, 0,2 % Mn, balance Fe.

f Pre-alloy base powder with a nominal composition 3,0 % Cr, 0,5 % Mo, 0,2 % Mn, balance Fe.

g Machined test pieces according to ISO 3928.

h As-sintered test pieces (sintered surfaces) according to ISO 3928.

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Table 13 — Ferrous materials for structural parts: pre-alloyed steels — Heat-treated

Grade[a]	Normative values								Informative values											
	Chemical composition							Ultimate tensile strength min.	Density	Tensile strength[f]	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[i]	Bending fatigue limit 90 % survival[i]	Apparent hardness	
	C combined	Ni	Mo	Cr	Mn	Fe	Total other elements max.													
	%	%	%	%	%	%	%	R_m MPa	ρ g/cm^3	R_m MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	HV10	Rockwell
-FL-05M1N-690H[b,g]	0,4 to 0,7	0,35 to 0,55	0,50 to 0,85		0,20 to 0,40	Balance	2	690	6,8	760	<1	130	0,27	9	760	1 100	260		340	32 HRC
-FL-05M1N-830H[b,g]	0,4 to 0,7	0,35 to 0,55	0,50 to 0,85		0,20 to 0,40	Balance	2	830	7,0	900	<1	140	0,27	11	970	1 280	300		380	36 HRC
-FL-05M1N-970H[b,g]	0,4 to 0,7	0,35 to 0,55	0,50 to 0,85		0,20 to 0,40	Balance	2	970	7,2	1 030	<1	155	0,28	16	1 170	1 480	340		420	39 HRC
-FL-05M1-770H[c,g]	0,4 to 0,7		0,75 to 0,95		0,05 to 0,30	Balance	2	770	6,8	840	<1	130	0,27	8	1 000	1 240	260		305	26 HRC
-FL-05M1-940H[c,g]	0,4 to 0,7		0,75 to 0,95		0,05 to 0,30	Balance	2	940	7,0	1 020	<1	140	0,27	10	1 140	1 480	310		350	32 HRC
-FL-05M1-1120H[c,g]	0,4 to 0,7		0,75 to 0,95		0,05 to 0,30	Balance	2	1 120	7,2	1 190	<1	155	0,28	15	1 270	1 750	360		380	36 HRC
-FL-05N2M-720H[d,g]	0,4 to 0,7	1,75 to 2,00	0,45 to 0,60		0,05 to 0,30	Balance	2	720	6,8	800	<1	130	0,27	9	830	1 190	275		340	30 HRC
-FL-05N2M-860H[d,g]	0,4 to 0,7	1,75 to 2,00	0,45 to 0,60		0,05 to 0,30	Balance	2	860	7,0	930	<1	140	0,27	12	1 000	1 390	330		380	35 HRC
-FL-05N2M-970H[d,g]	0,4 to 0,7	1,75 to 2,00	0,45 to 0,60		0,05 to 0,30	Balance	2	970	7,2	1 070	<1	155	0,28	16	1 170	1 590	370		420	39 HRC

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Table 13 (*continued*)

Grade[a]	Normative values								Informative values											
	Chemical composition							Ultimate tensile strength min.	Density	Tensile strength[f]	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[i]	Bending fatigue limit 90 % survival[j]	Apparent hardness	
	C combined	Ni	Mo	Cr	Mn	Fe	Total other elements max.													
	%	%	%	%	%	%	%	R_m MPa	ρ g/cm³	R_m MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	HV10	Rockwell
-FL-05Cr3M-830SH e,h	0,4 to 0,6		0,40 to 0,60	2,7 to 3,3	0,05 to 0,30	Balance	2	830	6,8	900	<1	130	0,27	12	930	1 520	230		340	30 HRC
-FL-05Cr3M-930SH e,h	0,4 to 0,6		0,40 to 0,60	2,7 to 3,3	0,05 to 0,30	Balance	2	930	7,0	1 000	<1	140	0,27	14	1 030	1 830	280		380	35 HRC
-FL-05Cr3M-1030SH e,h	0,4 to 0,6		0,40 to 0,60	2,7 to 3,3	0,05 to 0,30	Balance	2	1 030	7,2	1 100	<1	155	0,28	16	1 170	2 140	340		430	40 HRC

As-heat-treated tensile properties were derived from machined test bars according to ISO 2740.

a These materials are produced from pre-alloyed powders with the addition of elemental graphite.

b Pre-alloy base powder with a nominal composition 0,45 % Ni, 0,7 % Mo, 0,35 % Mn, balance Fe.

c Pre-alloy base powder with a nominal composition 0,85 % Mo, 0,2 % Mn, balance Fe.

d Pre-alloy base powder with a nominal composition 1,8 % Ni, 0,5 % Mo, 0,2 % Mn, balance Fe.

e Pre-alloy base powder with a nominal composition 3,0 % Cr, 0,5 % Mo, 0,2 % Mn, balance Fe.

f Tensile yield strength and ultimate tensile strength are approximately the same for heat-treated materials.

g Austenitized for 30 min at 850 °C in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered for 1 h at 180 °C.

h SH are materials produced by the Sinter Hardening Process; -FL-05Cr3M- is tempered at 180°C.

i Machined test pieces according to ISO 3928.

j As-sintered test pieces (sintered surfaces) according to ISO 3928.

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Table 14 — Ferrous materials for structural parts: hybrid-alloy steels — As sintered

Grade[a]	Normative values: Chemical composition C combined	Ni	Mo	Mn	Cu	Fe	Total other elements max.	Tensile yield strength min.	Informative values: Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[f]	Bending fatigue limit 90 % survival[g]	Axial fatigue limit 90 % survival[h]	Apparent hardness	
	%	%	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm³	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	MPa	HV5	Rockwell
-FLA-05M1-N2C-430[b]	0,4 to 0,7	1,55 to 1,95	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7	Balance	2	430	6,8	550	465	1	130	0,27	12	395	1 100			160	185	82 HRB
-FLA-05M1-N2C-465[b]	0,4 to 0,7	1,55 to 1,95	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7	Balance	2	465	7,0	670	500	2	140	0,27	18	430	1 290			190	200	86 HRB
-FLA-05M1-N2C-495[b]	0,4 to 0,7	1,55 to 1,95	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7	Balance	2	495	7,2	780	535	3	155	0,28	28	470	1 470			230	220	90 HRB
-FLA-05M1-N4C-500[b]	0,4 to 0,7	3,6 to 4,4	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7	Balance	2	500	6,8	640	555	<1	130	0,27	17	450	1 270			170	200	86 HRB
-FLA-05M1-N4C-535[b]	0,4 to 0,7	3,6 to 4,4	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7	Balance	2	535	7,0	740	580	<1	140	0,27	26	485	1 500			220	225	91 HRB
-FLA-05M1-N4C-570[b]	0,4 to 0,7	3,6 to 4,4	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7	Balance	2	570	7,2	840	600	1	155	0,28	43	520	1 720			265	250	96 HRB
-FLA-05M1N-N1-310[c]	0,4 to 0,7	1,35 to 2,50	0,50 to 0,85	0,20 to 0,40		Balance	2	310	6,8	460	360	1	130	0,27	11	340	8 60	190			150	83 HRB
-FLA-05M1N-N1-335[c]	0,4 to 0,7	1,35 to 2,50	0,50 to 0,85	0,20 to 0,40		Balance	2	335	7,0	490	390	1,5	140	0,27	17	380	1 000	215			160	88 HRB
-FLA-05M1N-N1-360[c]	0,4 to 0,7	1,35 to 2,50	0,50 to 0,85	0,20 to 0,40		Balance	2	360	7,2	560	420	2	155	0,28	25	400	1 140	250			175	95 HRB
-FLA-05M1-N2-340[d]	0,4 to 0,7	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30		Balance	2	340	6,8	450	400	1	130	0,27	9	380	1 070	170			175	80 HRB

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Table 14 (*continued*)

Grade [a]	Normative values: Chemical composition: C combined %	Ni %	Mo %	Mn %	Cu %	Fe %	Total other elements max. %	Tensile yield strength min. $R_{p0,2}$ MPa	Informative values: Density ρ g/cm³	Tensile strength R_m MPa	Tensile yield strength $R_{p0,2}$ MPa	Elongation A_{25} %	Young's modulus GPa	Poisson's ratio	Unnotched Charpy impact J	Compressive yield strength (0,1 %) MPa	Transverse rupture strength MPa	Rotating fatigue limit 90 % survival[f] MPa	Bending fatigue limit 90 % survival[g] MPa	Axial fatigue limit 90 % survival[h] MPa	Apparent hardness HV5	Apparent hardness Rockwell
-FLA-05M1-N2-370[d]	0,4 to 0,7	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30		Balance	2	370	7,0	530	430	1,5	140	0,27	15	420	1 260	210			190	84 HRB
-FLA-05M1-N2-400[d]	0,4 to 0,7	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30		Balance	2	400	7,2	620	460	2	155	0,28	24	460	1 435	255			210	87 HRB
-FLA-05M1-N4-480[d]	0,4 to 0,7	3,0 to 5,0	0,65 to 0,95	0,05 to 0,30		Balance	2	480	6,8	570	530	<1	130	0,27	11	380	970	190			185	83 HRB
-FLA-05M1-N4-570[d]	0,4 to 0,7	3,0 to 5,0	0,65 to 0,95	0,05 to 0,30		Balance	2	570	7,0	680	630	<1	140	0,27	15	410	1 240	215			210	86 HRB
-FLA-05M1-N4-660[d]	0,4 to 0,7	3,0 to 5,0	0,65 to 0,95	0,05 to 0,30		Balance	2	660	7,2	790	730	<1	155	0,28	27	440	1 510	245			245	90 HRB
-FLD-08M2-N2-500[e]	0,6 to 0,9	1,8 to 2,2	1,30 to 1,70	0,05 to 0,30		Balance	2	500	6,8	590	560	<1	130	0,27	10	420	1 150	200	200		260	92 HRB
-FLD-08M2-N2-570[e]	0,6 to 0,9	1,8 to 2,2	1,30 to 1,70	0,05 to 0,30		Balance	2	570	7,0	700	630	<1	140	0,27	14	480	1 380	230	220		280	95 HRB
-FLD-08M2-N2-640[e]	0,6 tp 0,9	1,8 to 2,2	1,30 to 1,70	0,05 to 0,30		Balance	2	640	7,2	830	710	1	155	0,28	21	540	1 650	260	240		340	99 HRB
-FLD-05M2-N4C-360[e]	0,3 to 0,6	3,6 to 4,4	1,30 to 1,70	0,05 to 0,30	1,6 to 2,4	Balance	2	360	6,8	620	415	1	130	0,27	14	360	1 160				210	86 HRB

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Table 14 (*continued*)

Grade[a]	Normative values								Informative values													
	Chemical composition: C combined	Ni	Mo	Mn	Cu	Fe	Total other elements max.	Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[f]	Bending fatigue limit 90 % survival[g]	Axial fatigue limit 90 % survival[h]	Apparent hardness	
	%	%	%	%	%	%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	MPa	HV5	Rockwell
-FLD-05M2-N4C-430 [e]	0,3 to 0,6	3,6 to 4,4	1,30 to 1,70	0,05 to 0,30	1,6 to 2,4	Balance	2	430	7,0	755	480	1	140	0,27	17	420	1 420				250	91 HRB
-FLD-05M2-N4C-500 [e]	0,3 to 0,6	3,6 to 4,4	1,30 to 1,70	0,05 to 0,30	1,6 to 2,4	Balance	2	500	7,2	890	545	1,5	155	0,28	30	470	1 680				320	97 HRB

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

a These materials are produced from pre-alloyed powders plus addition or diffusion-alloyed elemental metal powders and graphite.

b Pre-alloy base powder with a nominal composition 0,5 % Mo, 0,2 % Mn, balance Fe.

c Pre-alloy base powder with a nominal composition 0,7 % Mo, 0,45 % Ni, 0,35 % Mn, balance Fe.

d Pre-alloy base powder with a nominal composition 0,85 % Mo, 0,2 % Mn, balance Fe.

e Pre-alloy base powder with a composition 1,5 % Mo, 0,2 % Mn, balance Fe.

f Machined test pieces according to ISO 3928.

g As-sintered test pieces (sintered surfaces) according to ISO 3928.

h Machined test pieces according to ISO 3928.

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Table 15 — Ferrous materials for structural parts: hybrid-alloy steels — Heat-treated

Grade [a]	Normative values									Informative values												
	Chemical composition								Ultimate tensile strength min.	Density	Tensile strength[n]	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[k]	Bending fatigue limit 90 % survival[l]	Axial fatigue limit 90 % survival[m]	Apparent hardness
	C combined	Ni	Mo	Mn	Cu	Cr	Fe	Total other elements max.														
	%	%	%	%	%		%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	MPa	HV10 / Rockwell
-FLA-05M1-N2C-830H[bi]	0,4 to 0,7	1,55 to 1,95	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7		Balance	2	830	6,8	900		<1	130	0,27	9	800	1 430			220	315 / 27 HRC
-FLA-05M1-N2C-1060H[bi]	0,4 to 0,7	1,55 to 1,95	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7		Balance	2	1 060	7,0	1 140		<1	140	0,27	15	980	1 800			300	350 / 32 HRC
-FLA-05M1-N2C-1280H[bi]	0,4 to 0,7	1,55 to 1,95	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7		Balance	2	1 280	7,2	1 410		<1	155	0,28	21	1 170	2 200			380	390 / 36 HRC
-FLA-05M1-N4C-860H[bi]	0,4 to 0,7	3,6 to 4,4	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7		Balance	2	860	6,8	930	800	<1	130	0,27	13	740	1 400			245	290 / 23 HRC
-FLA-05M1-N4C-1050H[bi]	0,4 to 0,7	3,6 to 4,4	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7		Balance	2	1 050	7,0	1 130	950	<1	140	0,27	18	880	1 735			310	315 / 27 HRC
-FLA-05M1-N4C-1260H[bi]	0,4 to 0,7	3,6 to 4,4	0,4 to 0,6	0,05 to 0,30	1,3 to 1,7		Balance	2	1 260	7,2	1 360	1080	<1	155	0,28	28	1 010	2 060			380	350 / 32 HRC
-FLA-05M1N-N1-720H[ch]	0,4 to 0,7	1,35 to 2,50	0,50 to 0,85	0,20 to 0,40			Balance	2	720	6,8	790		<1	130	0,27	9	1 000	1 170	260			340 / 30 HRC
-FLA-05M1N-N1-920H[ch]	0,4 to 0,7	1,35 to 2,50	0,50 to 0,85	0,20 to 0,40			Balance	2	920	7,0	980		<1	140	0,27	11	1 140	1 500	310			380 / 35 HRC
-FLA-05M1N-N1-1110H[ch]	0,4 to 0,7	1,35 to 2,50	0,50 to 0,85	0,20 to 0,40			Balance	2	1 110	7,2	1 180		1	155	0,28	16	1 280	1 830	360			430 / 40 HRC
-FLA-05M1-N2-830H[dh]	0,4 to 0,7	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30			Balance	2	830	6,8	900		<1	130	0,27	8	860	1 450	280			350 / 32 HRC
-FLA-05M1-N2-1040H[dh]	0,4 to 0,7	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30			Balance	2	1 040	7,0	1 120		<1	140	0,27	13	1 050	1 740	330			400 / 37 HRC
-FLA-05M1-N2-1230H[dh]	0,4 to 0,7	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30			Balance	2	1 230	7,2	1 340		<1	155	0,28	16	1 240	2 040	380			450 / 42 HRC
-FLA-05M1-N4-830H[dh]	0,4 to 0,7	3,0 to 5,0	0,65 to 0,95	0,05 to 0,30			Balance	2	830	6,8	900		<1	130	0,27	11	720	1 260	260			300 / 25 HRC
-FLA-05M1-N4-1070H[dh]	0,4 to 0,7	3,0 to 5,0	0,65 to 0,95	0,05 to 0,30			Balance	2	1 070	7,0	1 140		<1	140	0,27	15	890	1 620	320			340 / 30 HRC
-FLA-05M1-N4-1260H[dh]	0,4 to 0,7	3,0 to 5,0	0,65 to 0,95	0,05 to 0,30			Balance	2	1 260	7,2	1 370		<1	155	0,28	21	1 060	1 980	390			390 / 36 HRC

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Table 15 (*continued*)

Grade[a]	Normative values									Informative values													
	Chemical composition								Ultimate tensile strength min.	Density	Tensile strength[n]	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[k]	Bending fatigue limit 90 % survival[l]	Axial fatigue limit 90 % survival[m]	Apparent hardness	
	C combined	Ni	Mo	Mn	Cu	Cr	Fe	Total other elements max.															
	%	%	%	%	%		%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	MPa	HV10	Rockwell
-FLA-08M1-N2C2-590SH[dj]	0,6 to 0,9	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30	1,0 to 3,0		Balance	2	590	6,8	660		<1	130	0,27	9	590	1 310	180			280	21 HRC
-FLA-08M1-N2C2-720SH[dj]	0,6 to 0,9	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30	1,0 to 3,0		Balance	2	720	7,0	790		<1	140	0,27	16	660	1 520	230			300	25 HRC
-FLA-08M1-N2C2-900SH[dj]	0,6 to 0,9	1,0 to 3,0	0,65 to 0,95	0,05 to 0,30	1,0 to 3,0		Balance	2	900	7,2	970		1	155	0,28	22	720	1 720	290			340	30 HRC
-FLA-08N2M-C2-480SH[ej]	0,6 to 0,9	1,6 to 2,00	0,45 to 0,60	0,05 to 0,30	1,0 to 3,0		Balance	2	480	6,8	550		<1	130	0,27	9		1 030	160			305	26 HRC
-FLA-08N2M-C2-620SH[ej]	0,6 to 0,9	1,6 to 2,00	0,45 to 0,60	0,05 to 0,30	1,0 to 3,0		Balance	2	620	7,0	690		<1	140	0,27	12		1 310	230			345	31 HRC
-FLA-08N2M-C2-760SH[ej]	0,6 to 0,9	1,6 to 2,00	0,45 to 0,60	0,05 to 0,30	1,0 to 3,0		Balance	2	760	7,2	830		<1	155	0,28	19		1 590	290			400	37 HRC
-FLA-06N1M-C-690SH[fj]	0,5 to 0,7	1,2 to 1,6	1,1 to 1,4	0,3 to 0,5	0,75 to 1,35		Balance	2	690	6,8	760		<1	130	0,27	9	900	1 380			190	330	29 HRC
-FLA-06N1M-C-970SH[fj]	0,5 to 0,7	1,2 to 1,6	1,1 to 1,4	0,3 to 0,5	0,75 to 1,35		Balance	2	970	7,0	1 030		<1	140	0,27	14	1 100	1 650			245	370	34 HRC
-FLA-06N1M-C-1210SH[fj]	0,5 to 0,7	1,2 to 1,6	1,1 to 1,4	0,3 to 0,5	0,75 to 1,35		Balance	2	1 210	7,2	1 280		<1	155	0,28	20	1 280	1 970			320	410	39 HRC
-FLA-08N1M-C2-590SH[fj]	0,6 to 0,9	1,2 to 1,6	1,1 to 1,4	0,3 to 0,5	1,0 to 3,0		Balance	2	590	6,8	620		<1	130	0,27	15	790	1 240			200	340	30 HRC
-FLA-08N1M-C2-760SH[fj]	0,6 to 0,9	1,2 to 1,6	1,1 to 1,4	0,3 to 0,5	1,0 to 3,0		Balance	2	760	7,0	830		<1	140	0,27	19	930	1 590			250	380	35 HRC
-FLA-08N1M-C2-1000SH[fj]	0,6 to 0,9	1,2 to 1,6	1,1 to 1,4	0,3 to 0,5	1,0 to 3,0		Balance	2	1 000	7,2	1 070		<1	155	0,28	23	1 100	1 860			295	430	40 HRC
-FLA-07Cr2M-C2-660SH[gj]	0,6 to 0,8		0,15 to 0,30	0,05 to 0,30	1,6 to 2,4	1,3 to 1,7	Balance	2	660	6,8	720	620	<1	130	0,27	12	760	1 590	260			310	27 HRC

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Table 15 (*continued*)

Grade[a]	Normative values									Informative values													
	Chemical composition								Ultimate tensile strength min.	Density	Tensile strength[n]	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[k]	Bending fatigue limit 90 % survival[l]	Axial fatigue limit 90 % survival[m]	Apparent hardness	
	C combined	Ni	Mo	Mn	Cu	Cr	Fe	Total other elements max.															
	%	%	%	%	%		%	%	$R_{p0,2}$ MPa	ρ g/cm³	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	MPa	MPa	HV10	Rockwell
-FLA-07Cr2M-C2-760SH[gj]	0,6 to 0,8		0,15 to 0,30	0,05 to 0,30	1,6 to 2,4	1,3 to 1,7	Balance	2	760	7,0	830	690	<1	140	0,27	15	830	1 760	320			340	30 HRC
-FLA-07Cr2M-C2-830SH[gj]	0,6 to 0,8		0,15 to 0,30	0,05 to 0,30	1,6 to 2,4	1,3 to 1,7	Balance	2	830	7,2	900	760	<1	155	0,28	18	900	1 930	380			360	33 HRC

As-heat-treated tensile properties were derived from machined test bars according to ISO 2740.

a These materials are produced from pre-alloyed powders with the addition of elemental metal powders and graphite.

b Pre-alloy base powder with a nominal composition 0,5 % Mo, 0,2 % Mn, balance Fe.

c Pre-alloy base powder with a nominal composition 0,45 % Ni, 0,7 % Mo, 0,35 % Mn, balance Fe.

d Pre-alloy base powder with a nominal composition 0,85 % Mo, 0,2 % Mn, balance Fe.

e Pre-alloy base powder with a nominal composition 1,8 % Ni, 0,5 % Mo, 0,2 % Mn, balance Fe.

f Pre-alloy base powder with a nominal composition 1,4 % Ni, 1,25 % Mo, 0,4 % Mn, balance Fe.

g Pre-alloy base powder with a nominal composition 1,5 % Cr, 0,25 % Mo, 0,2 % Mn, balance Fe.

h Austenitized for 30 min at 850 °C in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered for 1 h at 180 °C.

i Austenitized for 30 min at 850 °C in a protective atmosphere with a 0,5 % carbon potential, oil-quenched and tempered for 1 h at 205 °C.

j SH are materials produced by the Sinter Hardening Process; material name -FLA-08M1-N2C2 and -FLA-08N2M-C2 are tempered at 180°C. -FLA-06N1M-C and -FLA-08N1M-C2 are tempered at 205 °C.

k Machined test pieces according to ISO 3928.

l As-sintered test pieces (sintered surfaces) according to ISO 3928.

m Machined test pieces according to ISO 3928. Tempered for 1 h at 205 °C.

n Tensile yield strength and ultimate tensile strength are approximately the same for heat-treated materials.

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Table 16 — Ferrous materials for structural parts: copper-infiltrated steels

Grade	Normative values						Informative values											
	Chemical composition				Tensile yield strength min.	Ultimate tensile strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[d]	Apparent hardness	
	C combined[a]	Cu	Fe	Total other elements max.														
	%	%	%	%	$R_{p0,2}$ MPa	R_m MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV	Rockwell
-FX-08C10-340	0,6 to 0,9	8 to 15	Balance	2	340		7,3	600	410	3	160	0,28	14	490	1 140	230	210/5	89 HRB
-FX-08C20-410	0,6 to 0,9	15 to 25	Balance	2	410		7,3	550	480	1	145	0,24	9	480	1 080	160	210/5	90 HRB
-FX-08C10-760H[c]	0,6 to 0,9	8 to 15	Balance	2		760	7,3	830	b	<1	160	0,28	9	790	1 300	280	460/10	43 HRC
-FX-08C20-620H[c]	0,6 to 0,9	15 to 25	Balance	2		620	7,3	690	b	<1	145	0,24	7	510	1 100	190	390/10	36 HRC

Properties were derived from machined test bars according to ISO 2740.

All data are based on single-pass infiltration.

a On the basis of iron phase only.

b Tensile yield strength and ultimate tensile strength are approximately equal for heat-treated materials.

c Austenitized at 850 °C for 30 min in a protective atmosphere with a 0,8 % carbon potential, oil-quenched and tempered at 180 °C for 1 h.

d Machined test pieces according to ISO 3928.

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Table 17 — Ferrous materials for structural parts: austenitic, ferritic and martensitic steels

Type		Grade	Normative values										Informative values										
			Chemical composition								Tensile yield strength min	Ultimate tensile strength min	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival [g]	Apparent hardness	
			C combined	Cr	Ni	Mo	S	N	Fe	Total other elements max.														
			%	%	%	%	%	%	%	%	$R_{p0,2}$ MPa	R_m MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV	Rockwell
303	Austenitic	-FL303-170N[a]	<0,15	17 to 19	8 to 13		0,15 to 0,30	0,2 to 0,6	Balance	2	170		6,4	270	220	<1	105	0,25	5	260	590	90	120/5	62 HRB
303		-FL303-260N[b]	<0,15	17 to 19	8 to 13		0,15 to 0,30	0,2 to 0,6	Balance	2	260		6,9	470	310	10	140	0,27	47	320	n.m	145	180/5	70 HRB
304		-FL304-210N[a]	<0,08	18 to 20	8 to 12			0,2 to 0,6	Balance	2	210		6,4	300	260	<1	105	0,25	5	260	770	105	125/5	61 HRB
304		-FL304-260N[b]	<0,08	18 to 20	8 to 12			0,2 to 0,6	Balance	2	260		6,9	480	310	8	140	0,27	34	320	n.m	160	140/5	68 HRB
316		-FL316-170N[a]	<0,08	16 to 18	10 to 14	2 to 3		0,2 to 0,6	Balance	2	170		6,4	280	230	<1	105	0,25	7	250	740	75	115/5	59 HRB
316		-FL316-260N[b]	<0,08	16 to 18	10 to 14	2 to 3		0,2 to 0,6	Balance	2	260		6,9	480	310	13	140	0,27	65	320	n.m	130	125/5	65 HRB
316L		-FL316-150[c]	<0,03	16 to 18	10 to 14	2 to 3		<0,03	Balance	2	150		6,9	390	210	21	140	0,27	88	220	n.m	115	75/5	45 HRB
410L	Ferritic	-FL410-140[f]	<0,03	11,5 to 13,5			<0,03	<0,03	Balance	2	140		6,9	330	180	16	165	0,27	68	190	n.m	125	80/5	45 HRB
430L		-FL430-170[f]	<0,03	16 to 18			<0,03	<0,03	Balance	2	170		7,1	340	210	20	170	0,27	108	230	n.m	170	80/5	45 HRB
434L		-FL434-170[f]	<0,03	16 to 18		0,75 to 1,25	<0,03	<0,03	Balance	2	170		7,0	340	210	15	165	0,27	88	230	n.m	150	95/5	50 HRB

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Table 17 (*continued*)

Type		Grade	Normative values										Informative values											
			Chemical composition								Tensile yield strength min	Ultimate tensile strength min	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Rotating fatigue limit 90 % survival[g]	Apparent hardness	
			C combined	Cr	Ni	Mo	S	N	Fe	Total other elements max.														
			%	%	%	%	%	%	%	%	$R_{p0,2}$ MPa	R_m MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	MPa	HV	Rockwell
410	Martensitic	-FL410-620H[d]	0,10 to 0,25	11,5 to 13,5			<0,03	0,2 to 0,6	Balance	2		620	6,5	720	e	<1	125	0,25	3	640	780	240	300/10	23 HRC

n.m = not measurable.

The corrosion properties of sintered stainless steel are not necessarily the same as those of wrought stainless steels. In general, the austenitic materials can be ranked as type 316L being the best, followed by 304 and then 303. These materials as a group are all better than any of the martensitic or ferritic materials. Type 434 has the best corrosion properties of the latter group.

Sintering may also affect corrosion resistance, so that grade -FL 316-150 may be more resistant than the grades sintered in nitrogen-containing atmospheres.

Before using any sintered stainless steel, a corrosion test under expected environmental conditions is recommended.

NOTES: Property data were obtained under the following conditions:

a Grades -FL303-170N, -FL304-210N and -FL316-170N sintered in a nitrogen-containing atmosphere, e.g. dissociated ammonia at 1 150 °C.

b Grades -FL303-260N, -FL304-260N and -FL316-260N sintered in a nitrogen-containing atmosphere, e.g. dissociated ammonia at 1 290 °C.

c Grade -FL316-150 sintered in a nitrogen-free atmosphere, e.g. hydrogen or vacuum backfilled with argon at 1 290 °C.

d Grade FL410-620H sintered in a nitrogen-containing atmosphere, e.g. dissociated ammonia at 1 150 °C, hardened by rapid cooling, and tempered at 180 °C for 1 h.

e Tensile yield strength and ultimate tensile strength are approximately the same for heat-treated materials.

f Grades -FL410-140, -FL430-170 and -FL434-170 sintered in a nitrogen-free atmosphere, e.g. hydrogen or vacuum backfilled with argon at 1 290 °C

g Machined test pieces according to ISO 3928.

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Table 18 — Non-ferrous materials for structural parts: copper-based alloys

Grade		Normative values						Informative values										
		Chemical composition					Tensile yield strength min.	Density	Tensile strength	Tensile yield strength	Elongation	Young's modulus	Poisson's ratio	Unnotched Charpy impact	Compressive yield strength	Transverse rupture strength	Apparent hardness	
		Sn	Zn	Ni	Cu	Total other elements max.												
		%	%		%	%	$R_{p0,2}$ MPa	ρ g/cm^3	R_m MPa	$R_{p0,2}$ MPa	A_{25} %	GPa		J	(0,1 %) MPa	MPa	HV5	Rockwell
Brass	-CL-Z20-75		Balance		77 to 80	2	75	7,6	160	90	9	85	0,31	37	80	360	50	73 HRH
	-CL-Z20-80		Balance		77 to 80	2	80	8,0	240	120	18	100	0,31	61	100	480	68	82 HRH
	-CL-Z30-100		Balance		68 to 72	2	100	7,6	190	110	14	80	0,31	31	120	430	72	84 HRH
	-CL-Z30-110		Balance		68 to 72	2	110	8,0	230	130	17	90	0,31	52	130	590	84	92 HRH
Bronze	-C-T10-90R[a]	8,5 to 11,0			Balance	2	90	7,2	150	110	4	60	0,31	5	140	310	68	82 HRH
Nickel silver	-CL-N18Z-120		Balance	16 to 20	62 to 66	2	120	7,9	230	140	11	95	0,31	33	170	500	82	90 HRH

Properties were derived from pressed and sintered test pieces (not machined) according to ISO 2740.

a The letter R indicates that the material has been re-pressed.

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Annex A
(normative)

Designation system

A.1 Designation of materials

The designation system to be used for sintered materials specified in this International Standard is in accordance with the ISO/IEC Directives Part 2:2004. The objective is that the designation shall give an indication of the chemical composition of the sintered material and an indication of the way the raw material has been prepared.

A.2 Description block

The description block shall contain the letter P, denoting powder metallurgical materials.

A.3 Identity block

The identity block shall contain the number of this International Standard, ISO 5755, followed by the individual item block.

A.4 Individual item block

A.4.1 First group

The first group of the individual item block shall consist of one to three letters describing the base metal and ways of adding alloying elements:

— F = Plain iron powder or iron powder with admixed alloying additives;

— FD = Iron powder with diffusion-alloyed additives;

— FL = Pre-alloyed steel powder;

— FLA = Pre-alloyed steel powder with admixed alloying additives (hybrid-alloy steels);

— FLD = Pre-alloyed steel powder with diffusion-alloyed additives (hybrid-alloy steels);

— FX = Copper-infiltrated steel;

— C = Copper powder with admixed alloying additives;

— CL = Pre-alloyed copper-based powder.

A.4.2 Second group

The second group of the individual item block shall consist of two to six alphanumeric characters with two digits for the content of dissolved (combined) carbon without a decimal comma (except for copper-based materials and stainless steels, see examples under A.6), e.g. 03 = 0,3 % C. The third position in this group will

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be the capital letter assigned to the alloying element with the highest content (if any) followed by the nominal content given as integers, e.g. 1 = 0,5 % to 1,4 %, 2 = 1,5 % to 2,4 %, 10 = 10 % of the element in question. Finally, this group ends with the capital letter assigned to the alloying element with the second highest content (if any) but without any indication of the content.

A.4.3 Third group

The third group of the individual item block shall show the value of the minimum yield strength (or minimum tensile strength for heat-treated materials) listed as MPa, followed, if appropriate, by the letter H indicating heat-treated material, or letters SH for sinter-hardened material.

The individual item block shall start with a hyphen and the groups within the block shall be separated by a hyphen.

Special case for hybrid-alloy steels:

For these materials, where the pre-alloying is explained in the second group of the individual item block, an extra group shall be included after the second group showing the alloying elements that have been added by admixing (-FLA-) or diffusion-alloying (-FLD-). First the capital letter for the added element with the highest content followed by the content given with an integer and then the second added element (if any) without any indication of the content. In this case, the third group mentioned under A.4.3 becomes the fourth group.

A.5 Letters assigned to alloying elements

Letters assigned to alloying elements shall be as follows:

— C = Copper;

— Cr = Chromium;

— G = Graphite;

— M = Molybdenum;

— N = Nickel;

— P = Phosphorus;

— T = Tin;

— Z = Zinc.

A.6 Examples of the designation system

The description block (A.2) and the identity block (A.3) are not used in the tables of material specifications in this International Standard. They should be used on purchase and technical documentation where any possibility of ambiguity exists.

EXAMPLE 1 **-C-T10-K110** is a copper-based alloy with 10 % added tin, and a radial crushing strength, K, of 110 MPa.

EXAMPLE 2 **-F-08C2-620H** is an iron-based material with 0,8 % carbon, 2 % copper and a minimum tensile strength of 620 MPa in the heat-treated condition.

EXAMPLE 3 **-FD-05N4C-420** is an iron-based alloy with 0,5 % carbon and diffusion-alloyed additions of nickel (4 %) and copper having a minimum yield strength of 420 MPa.

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EXAMPLE 4 **-FL-05N2M-860H** is a pre-alloyed nickel (2 %) and molybdenum steel with 0,5 % carbon and a minimum tensile strength of 860 MPa in the heat-treated condition.

EXAMPLE 5 **-FX-08C20-410** is a copper-infiltrated iron-based material with 0,8 % carbon and a minimum yield strength of 410 MPa.

EXAMPLE 6 **-FL-304-260N** is a type 304 stainless steel, sintered in a nitrogen-containing atmosphere and having a minimum yield strength of 260 MPa. (Further information on the designation of stainless steels can be found in Table 16.)

EXAMPLE 7 **-FLA-05M1N-N1-360** is a hybrid-alloy steel based on pre-alloyed molybdenum (1 %) and nickel steel to which elemental nickel (1 %) has been added. It has 0,5 % carbon and a minimum yield strength of 360 MPa.

EXAMPLE 8 **-FLD-05M2-N4C-500** is a hybrid-alloy steel based on pre-alloyed molybdenum (1,5 %) to which nickel (4 %) and copper have been diffusion alloyed. It has 0,5 % carbon and a minimum yield strength of 500 MPa.

The description block (A.2) and the identity block (A.3) are not used in the tables of material specifications in this International Standard. They should be used on purchase and technical documentation where any possibility of ambiguity exists. Hence **P-ISO5755-FL-05Cr3M-670** is an example of a purchase order entry showing the International Standard number block in conjunction with the individual item block.

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Annex B
(informative)

Microstructures

For the preparation of samples for metallographic examination, reference should be made to ISO/TR 14321.

B.1 Bronze and bronze with graphite materials for bearings — Table 1

In 90-10 copper-tin bronze bearings, the structure should generally be alpha bronze with no grey copper-tin compounds and with a minimum of reddish copper-rich areas. For some applications, grey copper-tin compounds are permitted; this should be agreed between the producer and customer.

B.2 Iron, iron-copper, iron-bronze, iron-carbon-graphite materials for bearings — Table 2

In iron-copper bearings, the copper should have melted and flowed into the surrounding small pores. With copper contents $>$ 2 %, some free copper may be visible but with 2 % or less copper, free copper is generally not present. Bearings should show a minimum of original particle boundaries.

NOTE Some bearings specifically developed for noise reduction may contain free copper even though they contain 2 % or less copper; this should be agreed between the producer and customer. Such bearings will have lower strength values than those listed in Table 2.

The microstructure of iron-bronze combines the appearances of iron and bronze structures.

Iron-graphite material should exhibit either free graphite in its microstructure or a free-graphite/combined-carbon mixture, depending on the manufacturing process.

B.3 Iron and carbon steel materials for structural parts — Table 3

The carbon content of a sintered structure can be estimated metallographically from the area fraction of pearlite where 100 % pearlite is equivalent to approximately 0,8 % carbon. Carbon dissolves rapidly in iron and it is therefore unusual to see uncombined graphite after about 5 min sintering at 1 040 °C.

B.4 Copper steel and copper-carbon steel materials for structural parts — Table 4

Admixed copper powder melts at approximately 1 083 °C and flows between the iron particles and into small pores, helping the sintering mechanism. Normally, sintered alloys with 2 % or less copper show little or no undissolved copper. At higher percentages, the copper will be seen as a separate phase. Copper dissolves in iron but does not diffuse to the centre of the larger iron particles. When copper melts, it diffuses or migrates, leaving behind fairly large pores that can be easily seen in the microstructure. The combined carbon content may be estimated metallographically from the microstructure as described in B.3.

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B.5 Phosphorus steels for structural parts — Table 7

Phosphorus steels with less than 0,1 % carbon have predominantly ferritic structures. When etched in 4 % nital, it is possible to distinguish areas with high (lighter) and low (darker) phosphorus content. As carbon is increased, grey or dark areas of fine lamellar pearlite can be seen with light etching areas of ferrite. By adding copper, a network of copper-rich areas can be found in the microstructure. Well-rounded pores also characterize phosphorus steels.

B.6 Nickel steels for structural parts — Tables 8, 9

The fine nickel powder admixed with iron and graphite does not completely diffuse during conventional sintering. As-sintered nickel steels show light-coloured austenitic nickel-rich islands with needles of martensite or bainite around their edges. Sintering at temperatures above 1 150 °C will reduce the volume-fraction of nickel-rich islands. In the heat-treated condition, the nickel-rich islands are light coloured, austenitic at their centre and with martensitic needles at the edges (viewed at 1 000×). This heterogeneous structure is normal. The matrix is martensite and, depending on the quenching rate, 0 % to 35 % fine pearlite.

B.7 Diffusion-alloyed nickel-copper-molybdenum steels for structural parts — Tables 10, 11

These materials are produced from diffusion-alloyed powders with the addition of elemental graphite. These materials produce a heterogeneous microstructure. As-sintered diffusion-alloyed steels show a microstructure similar to the nickel steels in B.6 , but with a greater proportion of bainite and martensite. After heat treatment, the structures are similar to those of heat-treated nickel steels.

B.8 Pre-alloyed steels for structural parts — Tables 12, 13

These materials are produced from pre-alloyed steel powders with the addition of elemental graphite. After heat treatment, the pre-alloyed steels exhibit a uniform tempered martensitic structure.

B.9 Hybrid-alloy steels — Tables 14, 15

These materials are produced from pre-alloyed powder with elemental or diffusion-alloyed additions (such as nickel and/or copper). The resultant as-sintered microstructure consists of a heterogeneous mixture similar to the admixed or diffusion-alloyed steels with a difference in the form of the eutectoid product. Due to the pre-alloyed base powder, the eutectoid is not the same as the fine pearlite of the plain iron-carbon system. The carbide plates are coarser and spaced in such a manner that the proeutectoid ferrite is not clearly defined. Therefore, it is difficult to estimate the combined carbon content metallographically. Alloys containing copper additions may show bainite and/or martensite in the as-sintered structure. After heat treatment, the hybrid-alloy steels exhibit a tempered martensitic structure with nickel-rich areas in those alloys containing admixed or diffusion-alloyed nickel.

B.10 Copper or copper-alloy-infiltrated steels for structural parts — Table 16

The copper-rich phase can be seen clearly at 100× to 1 000×. The distribution of the copper phase through the part can be determined, and noted under infiltrated areas, if any exist. Although copper does not fill all the pores, it will fill first the finer interconnected pores by capillary action. The combined carbon content is based on the iron phase only.

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B.11 Austenitic, ferritic and martensitic stainless steels for structural parts — Table 17

The -FL303, -FL304 and -FL316 grades are austenitic with some evidence of twin formation. In the 316L type there should be little or no evidence of original particle boundaries, chromium carbides, nitrides or oxides.

The -FL410, -FL430 and -FL434 grades are ferritic in the as-sintered condition. There should be no evidence of prior particle boundaries, oxides or carbides. Even minor residual carbon or nitrogen will appear in the microstructure. The -FL410 heat-treated grade is fully martensitic after normal cooling from the sintering temperature. It also can be hardened separately but, in either case, is generally tempered for optimum toughness

B.12 Copper-based alloys for structural parts — Table 18

Brass, bronze and nickel-silver sinter to the point where very few original particle boundaries are observable. In well-sintered bronze, the alpha-bronze grains have grown from their original fine-grain clusters and there is no evidence of blue-grey intermetallic compounds.

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