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British Standard Specification for

Nickel and nickel alloys: bar

Spécification du nickel et des alliages de nickel: barres

Spezifikation für Nickel und Nickellegierungen: Stähe

British Standards Institution

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Foreword

This British Standard has been prepared under the direction of the Non-ferrous Metals Standards Policy Committee. It incorporates Amendment No. 1 issued in 1984 together with further technical changes but it does not reflect a full review or revision of the standard, which will be undertaken in due course. This edition of BS 3076 replaces BS 3076 : 1976 which is withdrawn.
It is one of a series for nickel and nickel alloys in various wrought forms intended for general engineering purposes. Others in the series are:

BS 3071 Specification for nickel copper alloy castings

BS 3072 Specification for nickel and nickel alloys: sheet and plate

BS 3073 Specification for nickel and nickel alloys: strip

BS 3074 Specification for nickel and nickel alloys: tube

BS 3075 Specification for nickel and nickel alloys: wire

When the standard was revised in 1976 all the alloys included in the previous edition were retained although details for the specific requirements were revised where necessary. Two additional alloys were introduced, to which new designations were assigned. As previously, the same designations were used throughout the series for wrought nickel and nickel alloys.
In this edition provision is made for testing material to alternative proof stress criteria, and in addition, for the supply of material to comply with a minimum proof stress requirement at one or more specified elevated temperatures, when requested by the purchaser. Additional proof stress requirements at room temperature and at elevated temperatures have been introduced for alloy NA21.

It is recommended that the results of elevated temperature tests together with information on the product dimensions, the room temperature tensile properties and the chemical composition of the material should be sent to:

Secretariat of NFM/10
British Standards Institution
3 York Street
MANCHESTER M2 2AT

so that, for future revisions of this standard, minimum elevated temperature proof stress values can be derived from a continuously updated data bank.

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

British Standard Specification for

Nickel and nickel alloys: bar

Section one. General requirements

1. Scope

This British Standard specifies requirements for nickel and nickel alloys in the form of:

(a) hot-worked round bar over 12 mm up to and including 300 mm diameter,

(b) cold-worked round bar over 8 mm up to and including 55 mm diameter, and

(c) cold-worked square, rectangular and hexagonal bar over 6 mm up to and including 55 mm wide across flats.

NOTE. Appendix A gives information on the heat treatment of alloys NA18 and NA20. Proof stress properties of cold worked and annealed and hot worked and annealed nickel alloy bars at elevated temperatures are given in appendix B. Appendix C gives the cross-references between the alloy designations in this standard and UNS designations.

2. References

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

3. Definitions

For the purposes of this British Standard the following definitions apply.

3.1 bar. A solid product of round, square, rectangular or hexagonal cross section.

3.2 cast. The product of a furnace melt, or of a number of melts that are mixed prior to casting.

3.3 batch. Bars of the same cross section from the same cast, produced in the same way and heat treated together.

3.4 annealing. A heat treatment of alloys for the purpose of softening.

3.5 solution treatment. The heat treatment of alloys at a suitable temperature for sufficient time to ensure adequate solution of a certain phase (or phases) followed by cooling at a suitable rate to ensure retention of the phase (or phases) in solution. The term is also associated with material in the softest condition.

3.6 precipitation treatment. The heat treatment of alloys to promote precipitation in order to produce optimum creep, or stress rupture and/or tensile characteristics. It may be accompanied by a change in hardness.

3.7 stress relief. The heat treatment of alloys to relieve the major portion of the internal stresses resulting from cold work.

4. Information to be supplied by the purchaser

The purchaser shall state the following at the time of the enquiry and order:

(a) the number of this British Standard and the designation of the material required (as given for the relevant material in section two);

(b) the section required (round, square, rectangular or hexagonal);

(c) dimensions, including appropriate lengths;

(d) the finish required (see section two);

(e) the condition of the material (see section two);

(f) whether cut lengths or random lengths are required;

(g) when required, whether 1.0 % proof stress values are to be determined in place of 0.2 % proof stress values (see clause **9**);

(h) whether a test certificate is required (see clause **10**);

(i) whether the purchaser desires to witness tests or inspections and, if so, which tests and/or inspections are to be witnessed (see clause **11**);

(j) the nature and details of any special requirements, including the method of marking (see clause **12**).

(k) whether the material to be supplied shall comply with a minimum 0.2 % or 1.0 % proof stress value at one or more specified elevated temperatures (selected from appendix B), and if so, at which temperature(s) (see **9.5**).

5. Freedom from defects

Cold-worked bars shall be clean, smooth and free from harmful defects. Hot-worked bars shall be smooth and free from harmful defects.

Surface defects occurring on hot-rolled or forged material may be removed by machining, if agreed between supplier and purchaser (see **7.1**).

6. Samples for chemical analysis

The chemical composition of each cast of material shall be determined on a sample that shall be representative of the cast.

7. Dimensional tolerances

7.1 Diameter (for round bar). The diameter of hot-worked or cold-worked round bar shall not differ from the specified diameter at any point by more than the appropriate tolerance specified in tables 1 or 2.

The tolerance on the diameter of machined round bar shall be +0.8 mm, −0 mm.

If necessary localized minor surface defects shall be dressed to a depth not exceeding 3 % of the diameter of the bar.

7.2 Width across flats (for square, rectangular and hexagonal bar). The width across flats shall not differ from that specified by more than the appropriate tolerance specified in table 3.

7.3 Length. The length shall not differ from that specified by more than the appropriate tolerance given in table 4.

7.4 Straightness. The depth of arc (deviation from straightness) shall not exceed the appropriate tolerance specified in table 5.

7.5 Ovality. For round bars, excluding those intended for subsequent forging, measurements of two diameters at right angles of any cross section shall not differ by more than half the total appropriate tolerance specified in tables 1 and 2 (see also **7.1**).

8. Selection of samples for mechanical tests

8.1 Selection of samples. All bars other than those intended for forging shall be grouped into batches. One test sample shall be cut from a bar selected from each batch. When tensile tests at elevated temperatures are to be carried out, one test sample shall be cut from each batch, of sufficient length to provide a tensile test piece for each test temperature.

Before test samples are cut they shall be marked to identify them with the batch they represent. Test samples shall be taken from the material as supplied and, except for material ordered in the hot-worked condition and in certain cases for alloys NA18 and NA20, shall be tested in that condition. Test samples from hot-worked material shall be appropriately heat treated before testing. No tests are required on bar intended for further forging.

Samples for mechanical test from alloys NA18 and NA20 supplied in other than the finally heat-treated condition shall be precipitation treated or solution treated and precipitation treated, as appropriate, using the conditions recommended by the supplier, which shall be within the ranges given in appendix A.

Table 1. Tolerances on diameter of hot-worked round bar

Diameter		Tolerance	
Over	Up to and including	Plus	Minus
mm	mm	mm	mm
12	25	0.4	0.4
25	50	0.8	0.4
50	100	1.2	0.8
100	110	3.2	1.6

NOTE. For tolerances on machined round bar of all diameters see **7.1**.

Table 2. Tolerances on diameter of cold-worked round bar

Diameter		Alloys NA11, NA12 and NA13		Alloys NA14, NA15, NA15(H) NA16, NA17, NA18 and NA21		Alloy NA20		Alloy NA20 (heat treated and descaled)	
Over	Up to and including	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus
mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
8.0	12.5	0	0.08	0	0.08	0	0.05	0.025	0.075
12.5	25	0	0.05	0.03	0.05	0	0.08	0.025	0.105
25	50	0	0.08	0.04	0.08	0	0.10	0.025	0.125
50	55	0	0.10	0.05	0.10	0	0.10	0.025	0.125

Table 3. Tolerances on width across flats of square, rectangular or hexagonal bar

Width across flats		Tolerance	
Over	Up to and including	Plus	Minus
mm	mm	mm	mm
5	25	0	0.08
25	38	0	0.10
38	50	0	0.13
50	55	0	0.15

Table 4. Tolerances on length of bar

Size		Tolerance	
Over	Up to and including	Plus	Minus
mm	mm	mm	mm
–	200	4	0
200	300	7	0

Table 5. Tolerances on straightness of bar

	Size	Depth of arc mm in any 500 mm
Cold-worked round bar	All sizes	1
Square, rectangular and hexagonal bar	All sizes	1.5
Hot-worked bar	All sizes	3

8.2 Location of test piece. For bars up to and including 30 mm diameter or width across flats, the test piece shall be machined coaxially from the test sample.

For bars over 30 mm up to and including 75 mm diameter or width across flats, the longitudinal axis of the test piece shall be taken not less than 15 mm from the surface of the test sample.

For bars over 75 mm diameter the test piece shall be taken longitudinally with the axis not less than 15 mm from the surface of the test sample or, at the option of the supplier, shall be taken in the transverse direction.

9. Mechanical tests

9.1 Tensile test. For the tensile test, test pieces shall be prepared and the test carried out in accordance with the requirements of BS 18 .

Values of 0.2 % proof stress are normally determined for acceptance purposes, but 1.0 % proof stress values may be determined if required by the purchaser and agreed at the time of the enquiry and order.

9.2 Stress-rupture test. When a stress-rupture test is required the test piece shall be prepared and the test carried out in accordance with the requirements of BS 3500 : Part 5.

9.3 Impact test. When a Charpy V-notch impact test is required the test piece shall be prepared and the test carried out in accordance with the requirements of BS 131 : Part 2.

9.4 Retests. If any one of the test pieces first selected fails to pass the mechanical tests, two further samples from the same batch shall be selected for testing, one of which shall be from the bar from which the original test sample was taken, unless that bar has been withdrawn by the supplier. If the test pieces from both these additional samples pass, the batch represented by the test samples shall be deemed to comply with the requirements of this standard. If the test pieces from either of these additional samples fail, the batch represented by these samples shall be deemed not to comply with the requirements of this standard.

9.5 Tensile tests at elevated temperatures. If required by the purchaser at the time of the enquiry and order (see item (k) in clause **4**), bars in alloys NA11, NA12, NA13, NA14, NA15, NA16 and NA21, all in the annealed condition, and alloy NA15(H) in the solution treated condition, shall be supplied to comply with a minimum 0.2 % or 1.0 % proof stress requirement at one or more specified elevated temperatures. In this case the elevated temperature tensile test pieces selected in accordance with clause **8** shall be prepared, and the tests carried out, in accordance with BS 3688 : Part 1 at the temperature(s) specified by the purchaser.

10. Test certificate

If required by the order, the supplier shall furnish with the material a certificate detailing the results of the chemical analysis and mechanical tests.

11. Inspection

Inspection of the material by the purchaser, if required, shall be as agreed between the purchaser and the supplier at the time of the enquiry and order.

12. Marking

12.1 Except as specified in **12.2** and at the option of the supplier, each bar shall be identified and the following information shall be legibly and indelibly marked either along the full length at intervals of not greater than 750 mm or at one end:

(a) the number of this British Standard, i.e. BS 3076;*

(b) the designation of the material (see section two);

(c) the supplier's name or trade mark;

(d) the batch or cast number.

12.2 For small bars that are bundled the information may be stamped on metal or other durable tags, one or more of which shall be securely attached to each bundle.

Any special requirements for marking shall be agreed between the purchaser and the manufacturer.

12.3 Any material used for marking shall be free from elements deleterious to the metal.

*Marking BS 3076 on or in relation to a product represents a manufacturer's declaration of conformity, i.e. a claim by or on behalf of the manufacturer that the product meets the requirements of the standard. The accuracy of the claim is therefore solely the responsibility of the person making the claim. Such a declaration is not to be confused with third party certification of conformity, which may also be desirable.

Section two. Specific requirements

13. NA11 nickel

13.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

13.2 Chemical composition. The chemical composition of the material shall be as given in table 6.

Table 6. Chemical composition of NA11 nickel

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	99.0	—
Copper	—	0.25
Iron	—	0.40
Carbon	—	0.15
Silicon	—	0.35
Manganese	—	0.35
Magnesium	—	0.20
Titanium	—	0.10
Sulphur	—	0.01

The percentage nickel content shall be determined as the difference between 100 and the sum of the contents of the other elements.

13.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser.

Round bar	Square, rectangular and hexagonal bar
Cold worked	Cold worked
Cold worked and annealed	Cold worked and annealed
Hot worked	
Hot worked and annealed	
Bar intended for further forging*	

13.4 Finish. Unless otherwise specified, material in the cold-worked condition shall be supplied with a smooth bright surface.

Material in the cold-worked and annealed condition shall be supplied with a dull matt or smooth bright surface.

Hot-worked material may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

13.5 Mechanical properties. The tensile properties at room temperature† obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 7.

13.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

Table 7. Tensile properties of NA11 nickel at room temperature

Condition	Size		0.2 % proof stress min.	1.0 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
	Over	Up to and including				
	mm	mm	N/mm^2 (=MPa)	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked	—	25	415	—	550	10
	25	55	345	—	520	14
Cold worked and annealed; Hot worked and annealed		All sizes	105	130	380	35

NOTE. Values of 0.2 % proof stress are normally determined for acceptance purposes (see **9.1**).

*Mechanical properties not applicable.

†In case of dispute room temperature is taken as 20 °C.

14. NA12 low-carbon nickel

14.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

NOTE. Under certain conditions of service, notably with fused caustic alkalis, some compositions within the range specified may be susceptible to stress corrosion cracking. When material is required for such duties the supplier should be informed.

14.2 Chemical composition. The chemical composition of the material shall be as given in table 8.

Table 8. Chemical composition of NA12 low-carbon nickel

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	99.0	–
Copper	–	0.25
Iron	–	0.40
Carbon	–	0.02
Silicon	–	0.35
Manganese	–	0.35
Magnesium	–	0.20
Titanium	–	0.10
Sulphur	–	0.01

The percentage nickel content shall be determined as the difference between 100 and the sum of the contents of the other elements.

14.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser.

Round bar	Square, rectangular and hexagonal bar
Cold worked and annealed	
Hot worked	Cold worked and annealed
Hot worked and annealed	
Bar intended for further forging*	

14.4 Finish. Unless otherwise specified, material in the cold-worked and annealed condition shall be supplied with a dull matt or a smooth bright surface.

Hot worked material may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

14.5 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 9.

Table 9. Tensile properties of NA12 low-carbon nickel at room temperature

Condition	Size	0.2 % proof stress min.	1.0 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
		N/mm^2 (=MPa)	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked and annealed Hot worked and annealed	All sizes	70	95	340	35

NOTE. Values of 0.2 % proof stress are normally determined for acceptance purposes (see **9.1**).

14.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

*Mechanical properties not applicable.

15. NA13 nickel-copper alloy

15.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

15.2 Chemical composition. The chemical composition of the material shall be as given in table 10.

Table 10. Chemical composition of NA13 nickel-copper alloy

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	63.0	–
Copper	28.0	34.0
Iron	–	2.5
Carbon	–	0.3
Silicon	–	0.5
Manganese	–	2.0
Sulphur	–	0.024

The percentage nickel content shall be determined as the difference between 100 and the sum of the contents of the other elements.

15.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser:

Round bar	Square, rectangular and hexagonal bar
Cold worked and annealed	Cold worked and annealed
Cold worked and stress relieved	Cold worked and stress relieved
Hot worked	
Hot worked and annealed	
Bar intended for further forging*	

15.4 Finish. Unless otherwise specified, material in the cold-worked and stress-relieved condition shall be supplied with a lightly oxidized surface condition.

Material in the cold-worked and annealed condition shall be supplied with a dull matt or a smooth bright surface.

Hot-worked material may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

15.5 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 11.

15.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

Table 11. Tensile properties of NA13 nickel-copper alloy at room temperature

Condition	Size	0.2 % proof stress min.	1.0 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
		N/mm^2 (=MPa)	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked and annealed	All sizes	170	195	480	35
Cold worked and stress relieved	*Round bars* Up to and including 40 mm dia.	415	–	600	20
	Over 40 mm up to and including 55 mm dia.	380	–	580	20
	Square, rectangular and hexagonal bars All sizes	345	–	580	20
Hot worked and annealed	All sizes	170	195	480	35

NOTE. Values of 0.2 % proof stress are normally determined for acceptance purposes (see **9.1**).

* Mechanical properties not applicable.

16. NA14 nickel-chromium-iron alloy

16.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

16.2 Chemical composition. The chemical composition of the material shall be as given in table 12.

Table 12. Chemical composition of NA14 nickel-chromium-iron alloy

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	72.0	—
Copper	—	0.5
Chromium	14.0	17.0
Iron	6.0	10.0
Carbon	—	0.15
Silicon	—	0.5
Manganese	—	1.0
Sulphur	—	0.015

The percentage nickel content shall be determined as the difference between 100 and the sum of the contents of the other elements.

16.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser:

Round bar	Square, rectangular and hexagonal bar
Cold worked	Cold worked
Cold worked and annealed	Cold worked and annealed
Hot worked	
Hot worked and annealed	
Bar intended for further forging*	

16.4 Finish. Unless otherwise specified, material in the cold-worked condition shall be supplied with a smooth bright surface.

Material in the cold-worked and annealed condition shall be supplied with the surface lightly oxidized or with the surface chemically or abrasively cleaned at the option of the supplier.

Hot-worked material may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide or chemically or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

16.5 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 13.

16.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

Table 13. Tensile properties of NA14 nickel-chromium-iron alloy at room temperature

Condition	Size		0.2 % proof stress min.	1.0 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
	Over	Up to and including				
	mm	mm	N/mm^2 (=MPa)	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked	—	12.5	620	—	830	7
	12.5	25.0	585	—	760	10
	25.0	55.0	550	—	720	12
Cold worked and annealed Hot worked and annealed	All sizes		240	265	550	30

NOTE. Values of 0.2 % proof stress are normally determined for acceptance purposes (see **9.1**).

*Mechanical properties not applicable.

17. NA15 and NA15(H) nickel-iron-chromium alloys

17.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish, mechanical properties and grain size.

17.2 Chemical composition. The chemical composition of the material shall be as given in table 14.

Table 14. Chemical composition of NA15 and NA15(H) nickel-iron-chromium alloys

Element	NA15		NA15(H)	
	min.	max.	min.	max.
	%	%	%	%
Nickel (including not more than 2 % cobalt)	30.0	35.0	30.0	35.0
Copper	–	0.75	–	0.75
Chromium	19.0	23.0	19.0	23.0
Aluminium	0.15	0.60	0.15	0.60
Carbon	–	0.10	0.05	0.10
Silicon	–	1.0	–	1.0
Manganese	–	1.5	–	1.5
Titanium	0.15	0.60	0.15	0.60
Iron	Remainder		Remainder	
Sulphur	–	0.015	–	0.015

17.3 Condition. Material shall be supplied in one of the following conditions:

Round bars	Square, rectangular and hexagonal bar
NA15 Cold worked and annealed Hot worked Hot worked and annealed Bar intended for further forging*	NA15 Cold worked and annealed
NA15(H) Cold worked and solution treated Hot worked and solution treated Bar intended for further forging*	NA15(H) Cold worked and solution treated

NOTE 1. For NA15, 'annealed' refers to material heat treated at a temperature of approximately 1000 °C. Such material is normally employed at service temperatures up to and including 590 °C.

NOTE 2. For NA15(H), 'solution treated' refers to material heat treated at a temperature of not less than 1150 °C. Such material is normally employed at service temperatures above 590 °C and where optimum resistance to stress rupture is desired.

17.4 Finish. Unless otherwise specified, cold-worked heat-treated material shall be supplied with the surface lightly oxidized or with the surface chemically or abrasively cleaned at the option of the supplier.

Hot-worked material may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent dark oxide or chemically or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

17.5 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 15.

17.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

17.7 Grain size. When tested in accordance with ASTM E 112†, the grain size of bars in alloy NA15(H), other than bars intended for forging, shall be ASTM 5 or coarser.

Table 15. Tensile properties of NA15 and NA15(H) nickel-iron-chromium alloys at room temperature

Alloy	Condition	Size	0.2 % proof stress min.	1.0 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
			N/mm^2 (=MPa)	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
NA15	Cold worked and annealed Hot worked and annealed	All sizes	205	235	520	30
NA15(H)	Cold worked and solution treated Hot worked and solution treated	All sizes	170	200	450	30

NOTE. Values of 0.2 % proof stress are normally determined for acceptance purposes (see **9.1**).

*Mechanical properties and grain size requirements not applicable.

†Copies of this American Society for Testing and Materials specification are obtainable from American Technical Publishers Ltd., 68a Wilbury Way, Hitchin, Herts, SG4 0TP.

18. NA16 nickel-iron-chromium-molybdenum alloy

18.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

NOTE. If subsequent fabrication involves heating the alloy the supplier should be consulted as under certain conditions such heating may impair the corrosion resistance. If required by the purchaser the material may be subjected to a test for susceptibility to intercrystalline corrosion, the conditions of which should be agreed between the supplier and the purchaser.

18.2 Chemical composition. The chemical composition of the material shall be as given in table 16.

Table 16. Chemical composition of NA16 nickel-iron-chromium-molybdenum alloy

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	38.0	46.0
Copper	1.5	3.0
Chromium	19.5	23.5
Molybdenum	2.5	3.5
Aluminium	–	0.20
*Carbon	–	0.05
Silicon	–	0.5
Manganese	–	1.0
*Titanium	0.6	1.2
Sulphur	–	0.03
Iron	Remainder	

*The titanium content should be at least 20 times the carbon content.

18.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser:

Round bar	Square, rectangular and hexagonal bar
Cold worked and annealed	Cold worked and annealed
Hot worked and annealed	
Bar intended for further forging†	

18.4 Finish. Unless otherwise specified, cold-worked material shall be supplied with the surface lightly oxidized or with the surface chemically or abrasively cleaned at the option of the supplier.

Hot-worked materials may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent dark oxide or chemically or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

18.5 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 17.

Table 17. Tensile properties of NA16 nickel-iron-chromium-molybdenum alloy at room temperature

Condition	Size	0.2 % proof stress* min.	1.0 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
		N/mm^2 (=MPa)	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked and annealed Hot worked and annealed	All sizes	220	250	590	30

NOTE. Values of 0.2 % proof stress are normally determined for acceptance purposes (see **9.1**).

18.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

†Mechanical properties not applicable.

19. NA17 nickel-iron-chromium-silicon alloy

19.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition and finish.

19.2 Chemical composition. The chemical composition of the material shall be as given in table 18.

Table 18. Chemical composition of NA17 nickel-iron-chromium-silicon alloy

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	34.5	41.0
Copper	–	0.5
Chromium	17.0	19.0
Carbon	–	0.10
Silicon	1.9	2.6
Manganese	0.8	1.5
Titanium	–	0.20
Iron	Remainder	
Sulphur	–	0.03

19.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser:

Round bars	Square, rectangular and hexagonal bar
Cold worked and annealed	Cold worked and annealed
Hot worked	
Hot worked and annealed	
Bar intended for further forging*	

19.4 Finish. Unless otherwise specified, cold-worked material shall be supplied with the surface lightly oxidized or with the surface chemically or abrasively cleaned at the option of the supplier.

Hot-worked material may be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent dark oxide or chemically or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

*Mechanical properties not applicable.

20. NA18 nickel-copper-aluminium alloy

20.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

20.2 Chemical composition. The chemical composition of the material shall be as given in table 19.

Table 19. Chemical composition of NA18 nickel-copper-aluminium alloy

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	63.0	–
Copper	27.0	33.0
Iron	–	2.0
Aluminium	2.3	3.2
Carbon	–	0.25
Silicon	–	0.5
Manganese	–	1.5
Titanium	0.35	0.85
Sulphur	–	0.01

The percentage nickel content shall be determined as the difference between 100 and the sum of the contents of the other elements.

20.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser:

Round bar

Cold worked
Cold worked and solution treated
Cold worked and precipitation treated
Cold worked, solution treated and precipitation treated
Hot worked
Hot worked and solution treated
Hot worked and precipitation treated
Hot worked, solution treated and precipitation treated
Bar intended for further forging*

Square, rectangular and hexagonal bar

Cold worked and solution treated
cold worked, solution treated and precipitation treated

Table 20. Tensile properties of NA18 nickel-copper-aluminium alloy at room temperature

Condition	Size		0.2 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
	Over	Up to and including			
	mm	mm	N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked and precipitation treated†	–	25	760	1000	14
	25	55	690	970	16
Cold worked, solution treated and precipitation treated	–	25	620	900	20
	25	55	585	900	20
Hot worked and precipitation treated	–	110	690	970	15
	110	300	550	830	15
Hot worked, solution treated and precipitation treated	–	25	620	900	20
	25	110	585	900	20
	110	300	500	830	15

*Mechanical properties not applicable.

†Applicable to round bars only.

20.4 Finish. Unless otherwise specified, round bar in the cold worked condition shall be supplied with a smooth bright surface. Material in the cold-worked and solution-treated condition shall be supplied with the surface lightly oxidized or with the surface chemically or abrasively cleaned at the option of the supplier.

Material in the hot-worked or hot-worked and solution-treated condition may be supplied with one of the following surface conditions:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide or chemically or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

Material that has been precipitation treated may be supplied with one of the following surface conditions:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

20.5 Heat treatment. This alloy is normally supplied and used in a heat-treated condition of which details are given in appendix A.

20.6 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 20.

21. NA20 nickel-chromium-titanium-aluminium alloy

21.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

NOTE. The recommended heat treatment and specified mechanical properties are applicable to material intended for bolts.

21.2 Chemical composition. The chemical composition of the material shall be as given in table 21.

Table 21. Chemical composition of NA20 nickel-chromium-titanium-aluminium alloy

Element	Min.	Max.
	%	%
Nickel (including not more than 2 % cobalt)	Remainder	
Copper	–	0.2
Chromium	18.0	21.0
Iron	–	1.5
Aluminium	1.0	1.8
Carbon	0.04	0.10
Silicon	–	1.0
Manganese	–	1.0
Titanium	1.8	2.7
Sulphur	–	0.015
Boron	–	0.008

21.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser:

Round bar

Cold worked
Cold worked and solution treated
Cold worked, solution treated and precipitation treated
Hot worked and solution treated
Hot worked, solution treated and precipitation treated
Bar intended for further forging*

Square, rectangular and hexagonal bar

Cold worked
Cold worked and solution treated
Cold worked, solution treated and precipitation treated

21.4 Finish. Unless otherwise specified, material in the cold-worked conditions shall be supplied with a smooth bright surface. Material in the cold-worked and solution-treated condition shall be supplied with the surface lightly oxidized or with the surface chemically or abrasively cleaned at the option of the supplier.

Material in the hot-worked or hot-worked and solution-treated condition shall be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide or chemically or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

Material that has been precipitation treated shall be supplied with one of the following surface finishes:

12 mm *up to and including* 110 mm *diameter.* Tightly adherent oxide or abrasively cleaned.

12 mm *up to and including* 300 mm *diameter.* Rough turned or ground.

*Mechanical properties not applicable.

21.5 Heat treatment. This alloy is normally supplied and used in a heat-treated condition of which details are given in appendix A. These conditions of heat treatment shall also be applicable to samples tested to meet the requirements of **21.6.**

21.6 Mechanical properties

21.6.1 *Tensile test.* The mechanical properties at room temperature obtained from pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 22.

Table 22. Tensile properties of NA 20 nickel-chromium-titanium-aluminium alloy at room temperature

Condition	Size	0.2 % proof stress min.	Tensile strength min.	Elongation on gauge length of $5.65\sqrt{S_o}$ min.
		N/mm^2 (=MPa)	N/mm^2 (=MPa)	%
Cold worked, solution treated, and two-stage precipitation treated	All sizes	620	1000	20
Hot worked, solution treated, and two-stage precipitation treated	All sizes	620	1000	20

21.6.2 *Stress-rupture test.* The stress-rupture properties obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 23.

Table 23. Stress-rupture properties of NA20 nickel-chromium-titanium-aluminium alloy

Sizes	Temperature	Stress min.	Time to rupture min.
	°C	N/mm^2	h
All	750	325	23

21.6.3 *Impact test.* The Charpy V-notch impact properties obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be not less than 15 J.

21.6.4 *Young's modulus.* The Young's modulus obtained from samples selected as specified in clause **8** shall be not less than 200×10^3 N/mm^2. The test method shall be as agreed between the purchaser and the supplier.

22. NA21 nickel-chromium-molybdenum-niobium alloy

22.1 General. Material shall comply with the general requirements given in section one and shall comply with the following requirements for chemical composition, condition, finish and mechanical properties.

22.2 Chemical composition. The chemical composition of the material shall be as given in table 24.

Table 24. Chemical composition of NA21 nickel-chromium-molybdenum-niobium alloy

Element	Min.	Max.
	%	%
Carbon	–	0.10
Manganese	–	0.50
Silicon	–	0.50
Phosphorus	–	0.015
Sulphur	–	0.015
Chromium	20.0	23.0
Niobium and tantalum	3.15	4.15
Cobalt (if determined)	–	1.00
Molybdenum	8.0	10.0
Iron	–	5.0
Aluminium	–	0.40
Titanium	–	0.40
Nickel	58.0	–

22.3 Condition. Material shall be supplied in one of the following conditions as specified by the purchaser.

Round bar

Cold worked and annealed
Cold worked and solution annealed
Hot worked and solution annealed
Hot worked and annealed
Bar intended for further forging*

22.4 Finish. Cold-worked material shall be supplied with the surface bright or lightly oxidized or with the surface chemically or abrasively cleaned.

Hot worked material shall be supplied with one of the following surface finishes:

12 mm up to and including 110 mm diameter. Tightly adherent oxide or chemically or abrasively cleaned.

12 mm up to and including 300 mm diameter. Rough turned or ground.

22.5 Mechanical properties. The tensile properties at room temperature obtained from test pieces selected and prepared as specified in clauses **8** and **9** shall be as given in table 25.

22.6 Tensile properties at elevated temperatures. When tensile tests at one or more specified elevated temperatures are required by the purchaser (see item (k) in clause **4**), then the proof stress properties obtained from test pieces selected, prepared and tested in accordance with clauses **8** and **9.5** shall be as given in appendix B for the specified temperature(s). For temperatures between those given in the table in appendix B, the minimum proof stress values for the next higher temperature shall apply.

NOTE. The proof stress values given in appendix B for temperatures other than those specified by the purchaser for testing, are not subject to verification and are given for information purposes only.

Table 25. Tensile properties of NA21 nickel-chromium-molybdenum-niobium alloy at room temperature

Condition	Size		0.2 % proof stress (min.)	1.0 % proof stress (min.)	Tensile strength (min.)	Elongation on gauge length of $5.65\sqrt{S_o}$ (min.)
	Over	Up to and including				
	mm	mm	N/mm^2	N/mm^2	N/mm^2	%
Cold worked and annealed Hot worked and annealed	–	100	415	455	830	30
Hot worked and annealed	100	–	345	385	760	25
Cold worked and solution annealed Hot worked and solution annealed	All sizes		275	–	690	30

* Mechanical properties not applicable.

Appendix A

Heat treatment of alloys NA18 and NA20

A.1 NA18 nickel-copper-aluminium alloy

A.1.1 *Solution treatment.* The material is normally solution treated by maintaining it at a temperature within the range 980 °C to 1050 °C for up to 30 min for each 25 mm of diameter or smallest dimension of a polygonal cross-section, followed by rapid cooling.

A.1.2 *Precipitation treatment.* The material is normally precipitation treated within the temperature range 500 °C to 600 °C for 6 h to 16 h, followed by furnace cooling to 480 °C at a rate between 8 °C/h and 14 °C/h. The rate of cooling below 480 °C is unimportant.

The heat treatment given to the material for demonstrating its response to precipitation treatment for specification purposes does not necessarily give the optimum properties for any particular application. By varying the time the material is maintained at the temperature, the degree of precipitation hardening can be altered; the advice of the supplier should be sought for any particular service condition.

A.2 NA20 nickel-chromium-aluminium-titanium alloy (for bolts)

A.2.1 *Solution treatment.* The material is normally solution treated by maintaining it at a temperature of 1080 °C for a period of up to 8 h and then cooling it in a suitable medium.

A.2.2 *Precipitation treatment.* The material is normally precipitation treated by

(a) maintaining it at a temperature of 850 °C for a period of 24 h and air cooling it, followed by

(b) maintaining it at a temperature of 700 °C for a period of up to 16 h.

The above conditions of heat treatment are particularly suitable when alloy NA20 is to be used for bolts for service at elevated temperatures. They should be applied to samples for mechanical testing to ensure that the material meets the requirements of **21.6**. Where the alloy is to be used at or near ambient temperatures or for other applications, different conditions of treatment may be appropriate and the user should seek the advice of the supplier.

Appendix B

Minimum proof stress properties of cold-worked and annealed and hot-worked and annealed nickel alloy bar at elevated temperatures

The elevated temperature properties given in table 26 are not requirements of material supplied to this standard unless the purchaser specifically requests a proof stress requirement at one or more particular temperatures (see (see **9.5** and item (k) of clause **4**). If such a request is made by the purchaser, then the minimum proof stress value appropriate to the material at the specified temperature(s) given in table 26 should be considered a requirement of this standard.

Table 26. Minimum proof stress properties of cold-worked and annealed and hot-worked and annealed nickel alloy bar at elevated temperatures

Designation	Diameter or width across flats mm	Proof stress %	Minimum proof stress in N/mm² (=MPa) at a temperature of							
			200 °C	300 °C	350 °C	400 °C	450 °C	500 °C	600 °C	650 °C
NA11	All	0.2	100	95	90	–	–	–	–	–
		1.0	125	120	115	–	–	–	–	–
NA12	All	0.2	65	60	60	55	50	50	40	30
		1.0	90	85	85	80	75	70	60	50
NA13	All	0.2	135	135	135	130	130	125	–	–
		1.0	155	155	155	150	150	145	–	–
NA14	All	0.2	190	175	170	170	165	165	160	–
		1.0	215	200	195	190	185	185	180	–
NA15	All	0.2	165	150	145	140	140	135	125	–
		1.0	195	180	175	170	165	160	150	–
NA15(H)	All	0.2	125	115	110	105	105	105	100	–
		1.0	155	145	140	135	130	130	125	–
NA16	All	0.2	190	180	175	170	165	165	–	–
		1.0	220	205	200	195	190	190	–	–
NA21	⩽ 100	0.2	340	330	330	330	330	330	315	–
		1.0	380	370	370	370	370	370	350	–
	> 100	0.2	285	275	275	275	275	275	260	–
		1.0	320	315	315	315	315	315	295	–

Appendix C

Cross-references between the alloy designations in this standard and those given in the Unified Numbering System (UNS)

Wide use is made internationally, for procurement purposes, of the alloy designations for nickel alloys given in the Unified Numbering System (UNS). Details of this system are given in 'Metals and Alloys in the Unified Numbering System' (4th edition), published jointly by the Society of Automotive Engineers and the American Society for Testing and Materials. Cross-references between the alloy designations used in this British Standard and the UNS designations are given, for information, in table 27.

Table 27. Cross-references between the alloy designations in this standard and the UNS designations

BS alloy designation	UNS alloy designation
NA11	N02200
NA12	N02201
NA13	N04400
NA14	N06600
NA15	N08800
NA15(H)	N08810
NA16	N08825
NA17	No equivalent
NA18	N05500
NA20	N07080
NA21	N06625

Standards publications referred to

BS 18	Method for tensile testing of metals (including aerospace materials)
BS 131	Methods for notched bar tests Part 2 The Charpy V-notch impact test on metals
BS 3500	Methods for creep and rupture testing of metals Part 5 Production acceptance tests
BS 3688	Methods for mechanical testing of metals at elevated temperatures Part 1 Tensile testing
†ASTM E112	Methods for determining average grain size

†Metals and alloys in the Unified Numbering System, published jointly by the Society of Automotive Engineers and the American Society for Testing and Materials

†Copies obtainable from American Technical Publishers Ltd., 68a Wilbury Way, Hitchin, Herts, SG4 0TP.

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