



Standard Specification for Welded Copper-Nickel Pipe¹

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1. Scope

1.1 This specification covers welded copper-nickel alloy pipe for general engineering purposes. The following alloys are covered:²

Copper Alloy UNS No. ²	Previously Used Designation	Nominal Composition, % Copper	Nickel
C70600	706	90	10
C71500	715	70	30

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 The following documents of the issue in effect on date of material purchase form a part of this specification to the extent referenced herein:

2.2 ASTM Standards:³

B 153 Test Method for Expansion (Pin Test) for Copper and Copper-Alloy Pipe and Tubing

B 601 Classification for Temper Designations for Copper and Copper Alloys—Wrought and Cast

E 8 Test Methods of Tension Testing of Metallic Materials

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E 75 Test Methods for Chemical Analysis of Copper-Nickel and Copper-Nickel-Zinc Alloys

E 243 Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes

E 255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition

¹ This specification is under the jurisdiction of ASTM Committee B05 on Copper and Copper Alloys and is the direct responsibility of Subcommittee B05.04 on Pipe and Tube.

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² The UNS system for copper and copper alloys (see Practice E 527) is a simple expansion of the former standard designation system accomplished by the addition of a prefix “C” and a suffix “00.” The suffix can be used to accommodate composition variations of the base alloy.

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard’s Document Summary page on the ASTM website.

E 527 Practice for Numbering Metals and Alloys (UNS)

2.3 Other Documents:

American Welding Society Specification A 5.6⁴

American Welding Society Specification A 5.7⁴

3. Terminology

3.1 Definitions:

3.1.1 *welded pipe*—product made from sheet, strip, or plate with a seam made by welding.

3.1.2 *flash or bead*—weld metal that protrudes beyond the normal wall, both inside and outside.

3.1.3 *scarfing*—the removing of flash or bead by a cutting operation.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *capable of*—as used in this specification, the test is not mandatory under the terms of this specification unless definitely specified in the purchase order; however, should subsequent testing by the purchaser establish that the material does not meet these requirements, the material may be rejected.

4. Ordering Information

4.1 Orders for material under this specification shall include the following information:

4.1.1 Copper Alloy UNS No. (Section 1 and Table 1),

4.1.2 Temper (Section 9),

4.1.3 Radiographic examination (Section 11),

4.1.4 Dimensions: diameter and wall thickness (see 12.3, section 12.4, and section 12.5),

4.1.5 Lengths: whether specific or stock (see section 12.6),

4.1.6 Quantity of each size,

4.1.7 If the product is to be subsequently welded (see Table 1 and Footnote D), and

4.1.8 Packing and marking (Section 20).

5. Types of Welded Pipe

5.1 *As-Welded*—Pipe that has been welded with no further work performed other than straightening or cutting to length, or both.

⁴ Available from The American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126.

TABLE 1 Chemical Requirements

Copper Alloy UNS No ^A	Composition, %								
	Copper ^B	Nickel ^C	Lead, ^D max	Iron	Zinc, ^D max	Manganese, max	Sulfur, max	Phosphorus, max	Other Named Elements
C70600	remainder	9.0–11.0	0.05	1.0–1.8	1.0	1.0	0.02	0.02	^D
C71500	remainder	29.0–33.0	0.05	0.40–1.0	1.0	1.0	0.02	0.02	^D

^A New designation established in accordance with Practice E 527.

^B Silver counting as copper.

^C Cobalt counting as nickel.

^D When the product is for subsequent welding applications and so specified by the purchaser, zinc shall be 0.50 % max, lead 0.02 % max, and carbon 0.05 % max.

5.2 *Welded and Annealed*—Welded pipe that has been annealed to produce a uniform grain size appropriate to the specified annealed temper.

5.3 *Welded and Cold Drawn*—Welded pipe with internal flash removed by scarfing, and subsequently cold drawn to conform to the specified temper.

5.4 *Fully Finished*—Welded pipe with internal and external flash removed by scarfing and the pipe or tube subsequently cold drawn over a mandrel and annealed as necessary to conform to the specified temper.

6. Chemical Composition

6.1 The material shall conform to the chemical requirements specified in Table 1.

6.2 These specification limits do not preclude the presence of other elements. Limits for unnamed elements may be established by agreement between manufacturer or supplier and purchaser.

6.2.1 For copper alloys in which copper is specified as the remainder, copper may be taken as the difference between the sum of all the elements analyzed and 100 %.

6.2.1.1 When all the elements in Table 1 are analyzed, their sum shall be 99.5 % minimum.

7. Flash

7.1 If the pipe is made by the high-frequency welding process, the external flash shall always be removed. The internal flash shall be treated as one of the following:

7.1.1 *IFI*—Internal flash to remain in the “as-welded” condition,

7.1.2 *IFR*—Internal flash to be removed by scarfing, or

7.1.3 *IFD*—Internal flash to be displaced.

7.2 Unless otherwise specified, the IFI condition will be furnished.

8. Filler Material

8.1 Filler material, if used in the welding process, shall conform to classification ECuNi of AWS Specification A5.6 or RCuNi of AWS Specification A5.7.

9. Temper

9.1 The pipe shall be supplied in any one of the following tempers as specified and shall meet the mechanical requirements of Table 2, Table 3, and Table 4:

9.1.1 As welded from annealed sheet, strip, or plate (WM50),

9.1.2 As welded from cold-worked sheet, strip, or plate (WM00, WM01, WM02, etc.).

9.1.3 Welded and annealed (WO50),

TABLE 2 Mechanical Requirements of As-Welded and Fully Finished Pipe When Furnished in the Annealed Temper (WO61)

Copper Alloy UNS No.	Outside Diameter, in. (mm)	Tensile Strength, min, ksi ^A (MPa ^B)	Yield Strength at 0.5 % Extension Under Load, min, ksi ^A (MPa ^B)	Elongation in 2 in. (50.8 mm), min, %
C70600	up to 4½ (114), incl	40 (275)	15 (105)	25.0
	over 4½ (114)	38 (260)	13 (90)	25.0
C71500	up to 4½ (114), incl	50 (345)	20 (140)	30.0
	over 4½ (114)	45 (310)	15 (105)	30.0

^A ksi = 1000 psi.

^B See Appendix X2.

TABLE 3 Mechanical Requirements of Welded and Cold-Drawn and Fully Finished Pipe in Drawn Tempers

Copper Alloy UNS No.	Outside Diameter, in. (mm)	Tensile Strength, min, ksi ^A (MPa ^B)	Yield Strength at 0.5 % Extension Under Load, min, ksi ^A (MPa ^B)	Elongation in 2 in. (50.8 mm), min, %
C71500	up to 2 (50.8), incl, for wall thicknesses up to 0.048 (1.21 mm), incl.	72 (495)	50 (345)	12.0
	for wall thicknesses over 0.048 in. (1.21 mm)	72 (495)	50 (345)	15.0

^A ksi = 1000 psi.

^B See Appendix X2.

TABLE 4 Mechanical Requirements of As-Welded Pipe

Copper Alloy UNS No.	Condition	Outside Diameter, in. (mm)	Tensile Strength, min, ksi (MPa)	Yield Strength at 0.5 % Extension Under Load, min, ksi (MPa)
C70600	welded from annealed strip	up to 4½ (114), incl	45 (310)	30 (205)
	welded from cold-rolled strip	up to 4½ (114), incl	54 (375)	45 (310)

9.1.4 Welded and cold drawn in either light drawn (Copper Alloy UNS No. C70600 only) or hard drawn, stress relieved (WR00), (WR04), or

9.1.5 Fully finished as annealed (WO61) light drawn (Copper Alloy UNS No. C70600 only), or hard drawn, stress relieved (WH00, WH04).

10. Dimensions and Permissible Variations

10.1 For purposes of determining conformance with the dimensional requirements prescribed in this specification, any measured value outside the specified limiting values for any dimension may be cause for rejection.

NOTE 1—Blank spaces in the tolerance tables indicate that the material is not generally available or that no tolerance has been established (see Appendix X1).

10.2 Outside Diameter Tolerances:

10.2.1 The outside diameter for round pipe furnished “as-welded,” “as-welded and drawn,” and “as-welded fully finished” shall conform to the tolerances in Table 5 except as noted in 10.2.2.

10.2.2 These outside diameter tolerances shall not apply to the “as-welded” pipe when measured across that portion which contains the weld zone.

10.3 Wall Thickness Tolerances:

10.3.1 The wall thickness of pipe furnished in drawn tempers or as fully finished shall conform to the tolerances shown in Table 6, except as noted in 10.3.2 and 10.3.3.

10.3.2 The tolerances of Table 6 shall not apply to that portion of the “as-welded” wall which contains the weld flash or bead.

10.3.3 The tolerances of Table 6 shall be increased by 100 % for that portion of the “as-welded” wall which contains the weld zone.

10.4 Lengths and Tolerances:

10.4.1 Pipe in straight lengths shall be furnished in stock lengths with ends included unless the order requires specific lengths or specific lengths with ends.

10.4.2 The tolerances for pipe furnished in straight lengths shall be as shown in Table 7.

10.4.3 The schedule for pipe furnished with specific or stock lengths with ends shall be in accordance with Table 8.

10.5 *Squareness of Cut*—The departure from squareness of the end of any pipe shall not exceed 0.016 in./in. (0.016 mm/mm) of diameter.

10.6 *Roundness*—The difference between the major and minor diameter of pipe as determined at any one cross section shall not exceed 3 % of the nominal outside diameter.

11. Workmanship, Finish, and Appearance

11.1 The pipe shall be free of defects of a nature that interferes with normal commercial applications. It shall be well cleaned and free of dirt.

12. Sampling and Number of Tests

12.1 *Sampling*—The lot size, portion size, and selection of pieces shall be as follows:

12.1.1 Lot Size:

Outside Diameter, in. (mm)	Lot Size, lb (kg)
Up to 4 (102), incl	10 000 (4550)
Over 4 (102)	20 000 (9100)

12.1.2 Portion Size:

No. of Pieces in Lot	No. of Sample Pieces to Be Taken
1 to 50	1
51 to 200	2
201 to 1500	3
Over 1500	0.2 % of the total number of pieces in the lot

12.2 *Chemical Analysis*—Samples for chemical analysis shall be taken in accordance with Practice E 255. Drillings, milling, and so forth, shall be taken in approximately equal weight from each of the sample pieces selected in accordance with 12.1.2 and combined into one composite sample. The minimum weight of composite sample for chemical analysis shall be 150 g divided into three equal parts.

12.2.1 Instead of sampling in accordance with Practice E 255, the manufacturer shall have the option of determining conformance to chemical composition as follows: Conformance shall be determined by the manufacturer by analyzing samples taken at the time the castings are poured or samples taken from the semifinished product. If the manufacturer determines the chemical composition of the material during the course of manufacture, he shall not be required to sample and analyze the finished product. The number of samples taken for determination of chemical composition shall be as follows:

12.2.1.1 When samples are taken at the time the castings are poured, at least one sample shall be taken for each group of castings poured simultaneously from the same source of molten metal.

12.2.1.2 When samples are taken from the semifinished product, a sample shall be taken to represent each 10 000 lb (4550 kg) or fraction thereof, except that not more than one sample shall be required per piece.

12.2.1.3 Due to the discontinuous nature of the processing of castings into wrought products, it is not practical to identify specific castings analysis with a specific quantity of finished material.

12.2.1.4 In the event that heat identification or traceability is required, the purchaser shall specify the details desired.

12.3 *Tension Tests*—For the tension tests a specimen shall be taken from each of the pieces selected in accordance with 12.1. The required tension tests shall be made on each of the specimens so selected.

13. Retests

13.1 If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

13.2 If the percentage elongation of any tension test specimen is less than that specified and any part of the fracture is outside the middle two thirds of the gage length or in a punched or scribed mark within the reduced section, a retest shall be allowed.

13.3 If the results of any test made to determine the mechanical properties fail to meet the specified limits, this test shall be repeated on each of two additional specimens taken

TABLE 5 Average Outside Diameter^A Tolerances

Specified Diameter, in. (mm)	Tolerances, plus and minus, ^B in. (mm) for Pipe of Copper Alloy UNS Nos. C70600, C71000, C71500
Over 2 to 3 (50.8 to 76.2), incl	0.005 (0.13)
Over 3 to 4 (76.2 to 102), incl	0.006 (0.15)
Over 4 to 5 (102 to 127), incl	0.008 (0.20)
Over 5 to 6 (127 to 152), incl	0.009 (0.23)
Over 6 to 8 (152 to 203), incl	0.010 (0.25)
Over 8 to 10 (203 to 254), incl	0.013 (0.33)
Over 10 to 12 (254 to 305), incl	0.015 (0.38)
Over 12 (305)	0.5 %

^A The average outside diameter of a pipe is the average of the maximum and minimum outside diameters, as determined at any one cross section.

^B If tolerances all plus or all minus are desired, double the values given.

TABLE 6 Wall Thickness Tolerances, in. (mm)

NOTE 1—*Maximum Deviation at Any Point:* The following tolerances are plus and minus; if tolerances all plus or all minus are desired, double the values given.

	Outside Diameter, in. (mm)					
	Up to 2½ (63.5), incl	Over 2½ to 4½ (63.5 to 114), incl	Over 4½ to 6½ (114 to 165), incl	Over 6½ to 9 (165 to 230), incl	Over 9 to 11½ (230 to 292), incl	Over 11½ (292)
To 0.017 (0.43), incl	0.0013 (0.0033)	...	...	...	...	...
Over 0.017 to 0.021 (0.43 to 0.53), incl	0.0015 (0.038)	...	...	...	...	...
Over 0.021 to 0.026 (0.53 to 0.66), incl	0.002 (0.051)	...	...	...	...	...
Over 0.026 to 0.037 (0.66 to 0.94), incl	0.0025 (0.064)	0.003 (0.076)	...	...	...	...
Over 0.037 to 0.050 (0.94 to 1.27), incl	0.003 (0.076)	0.0035 (0.089)	0.0035 (0.089)	...	...	...
Over 0.050 to 0.073 (1.27 to 1.85), incl	0.0035 (0.089)	0.004 (0.10)	0.004 (0.10)	0.007 (0.18)	...	...
Over 0.073 to 0.130 (1.85 to 3.30), incl	0.004 (0.10)	0.0045 (0.11)	0.0045 (0.11)	0.008 (0.20)	...	...
Over 0.130 to 0.205 (3.30 to 5.20), incl	0.0045 (0.11)	0.005 (0.12)	0.005 (0.12)	0.010 (0.25)	0.012 (0.30)	0.014 (0.36)
Over 0.205 to 0.300 (5.20 to 7.61), incl	0.005 (0.12)	0.006 (0.15)	0.006 (0.15)	0.012 (0.30)	0.014 (0.36)	0.018 (0.46)
Over 0.300 to 0.500 (7.61 to 12.7) and over	0.006 (0.15)	0.007 (0.18)	0.007 (0.18)	0.019 (0.48)	0.017 (0.43)	0.023 (0.58)

TABLE 7 Length Tolerances for Pipe Furnished in Straight Lengths^A

Length	Tolerances, in. (mm) Applicable Only to Full-Length Pieces
Specific Lengths:	
Up to 6 in. (152 mm), incl	¼ (1.6)
Over 6 in. to 2 ft (152 to 610 mm), incl	⅜ (2.4)
Over 2 to 6 ft (610 mm to 1.83 m), incl	½ (3.2)
Over 6 to 14 ft (1.83 to 4.27 m), incl	¾ (6.4)
Over 14 ft (4.27 m)	1 (13)
Specific lengths with ends	1 (25)
Stock lengths with or without ends	1 (25)

^A As stock lengths are cut and placed in stock in advance of orders, departure from this tolerance is not practicable.

TABLE 8 Schedule of Specific and Stock Lengths with Ends Included

Major Outside Dimensions, in. (mm)	Nominal Length, ft (m)	Shortest Permissible Length, ^A % of Nominal Length	Maximum Permissible Weight of Ends, % of Lot Weight
Up to 3 (76.2), incl	6 to 20 (1.85 to 6.10), incl	55	30
Over 3 to 3½ (76.2 to 88.9), incl	6 to 20 (1.85 to 6.10), incl	50	40

^A Expressed to the nearest ½ ft (150 mm).

from different pieces and the results of both of these tests shall comply with the specified requirements.

13.4 If the chemical analysis fails to conform to the specified limits, analysis shall be made on a new composite sample prepared from additional pieces selected in accordance with 13.1. The results of this retest shall comply with the specified requirements.

14. Expansion Test for Pipe

14.1 The annealed material shall be capable of (see 3.2.1) being expanded in accordance with Test Method B 153 to 30 %

of its outside diameter. Tube supplied in the “as welded” condition shall be expanded to 20 % of its outside diameter.

14.2 The annealed ends of pipe furnished end annealed shall be capable of being expanded 30 % of its outside diameter in accordance with Test Method B 153.

14.3 Pipe furnished in other tempers is not subject to this test.

15. Nondestructive Tests for Pipe

15.1 *Radiographic Examination*—Radiographic examination of the welds shall be as agreed upon.

15.2 *Eddy-Current Test*—Each pipe of nominal outside diameter within the capabilities of the eddy-current tester shall be subjected to an eddy-current test. Testing shall follow the procedures of Practice E 243. The pipe shall be passed through an eddy-current testing unit adjusted to provide information on the suitability of the material for the intended application.

15.2.1 Notch depth standards rounded to the nearest 0.001 in. (0.025 mm) shall be 22 % of the nominal wall thickness. The notch depth tolerance shall be ±0.0005 in. (0.013 mm).

15.2.1.1 Pipe that does not actuate the signaling device of the eddy-current tester shall be considered as conforming to the requirements of this test. Pipe with discontinuities indicated by the testing unit may be reexamined or retested, at the option of the manufacturer, to determine whether the discontinuity is cause for rejection. Signals that are found to have been caused by minor mechanical damage, soil, or moisture, shall not be cause for rejection of the pipe, provided the dimensions are still within prescribed limits and the pipe is suitable for its intended application.

15.3 *Other Nondestructive Tests*—The material shall be tested in the final size, and unless otherwise agreed upon by the manufacturer or supplier and purchaser, it may be tested prior to the final anneal or heat treatment when these heat treatments are required. By agreement between the manufacturer or

supplier and purchaser, testing of the material by one of the methods in 15.3.1 and 15.3.2 may be required.

15.3.1 *Hydrostatic Test*—When specified, the pipe shall withstand, without showing weakness or defects, an internal hydrostatic pressure sufficient to subject the material to a fiber stress of 7000 psi (48 MPa), determined by the following equation for thin hollow cylinders under tension. The pipe need not be tested at a hydrostatic pressure of over 1000 psig (7 MPa), unless so specified.

$$P = 2St(D - 0.8t) \quad (1)$$

where:

- P = hydrostatic pressure, psig (or MPa),
- t = wall thickness of the pipe, in. (or mm),
- D = outside diameter of the pipe, in. (or mm), and
- S = allowable stress of the material.

15.3.2 *Pneumatic Test*—When specified, the pipe shall be subjected to an internal air pressure of 60 psig (400 kPa) minimum for 5 s without showing evidence of leakage. The test method used shall permit easy visual detection of any leakage, such as by having the pipe under water or by the pressure-differential method. Any evidence of leakage shall be cause for rejection.

16. Test Methods

16.1 The properties enumerated in this specification shall, in case of disagreement, be determined in accordance with the following ASTM test methods:

Test	ASTM Designation
Chemical analysis	E 75
Tension test	E 8

16.2 Tension test specimens shall be of the full section of the pipe and shall conform to the requirements of Test Specimens section of Test Methods E 8, unless the limitations of the testing machine preclude the use of such a specimen. Test specimens conforming to Type No. 1 of Fig. 13, Tension Test Specimen for Large-Diameter Tubular Products, of Test Methods E 8 may be used when a full-section specimen cannot be tested.

16.3 Whenever tension test results are obtained from both full-size and from machined test specimens and they differ, the results obtained from full-size test specimens shall be used to determine conformance to the specification requirements.

16.4 Tension test results on material covered by this specification are not seriously affected by variations in speed of testing. A considerable range of testing speed is permissible; however, the rate of stressing to the yield strength should not

exceed 100 ksi (690 MPa)/min. Above the yield strength the movement per minute of the testing machine head under load should not exceed 0.5 in./in. (0.5 mm/mm) of gage length (or distance between grips for full-section specimens).

17. Significance of Numerical Limits

17.1 For purposes of determining compliance with the specified limits for requirements of the properties listed in the following table, and observed value or a calculated value shall be rounded as indicated in accordance with the rounding method of Practice E 29.

Property	Rounded Unit for Observed or Calculated Value
Chemical composition	nearest unit in the last right-hand place of figures of the specified limit
Tensile strength	nearest ksi (nearest MPa up to 10 ksi, incl, nearest 5 MPa over 10 ksi)
Yield strength	nearest 1 %
Elongation	nearest 1 %

18. Rejection and Rehearing

18.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the manufacturer or supplier promptly and in writing. In case of dissatisfaction with the results of the test, the manufacturer or supplier may make claim for a rehearing.

19. Certification

19.1 When specified on the purchase order, the manufacturer shall furnish to the purchaser a certificate stating that each lot has been sampled, tested, and inspected in accordance with this specification and has met the requirements.

19.2 When material is specified to meet the requirements of *ASME Boiler and Pressure Vessel Code*, the certification requirements are mandatory.

20. Packaging and Package Marking

20.1 The material shall be separated by size, composition, and temper, and prepared for shipment in such a manner as to ensure acceptance by common carrier for transportation and to afford protection from the normal hazards of transportation.

20.2 Each shipping unit shall be legibly marked with the purchase order number, metal or alloy designation, temper, size, shape, total length or piece count, or both, and name of supplier. The specification number shall be shown when specified.

21. Mill Test Report

21.1 When specified on the purchase order, the manufacturer shall furnish to the purchaser a test report showing results of tests required by the specification.

APPENDIXES
(Nonmandatory Information)
X1. SUGGESTED SIZES FOR PIPE

X1.1 Suggested wall thickness for welded copper-nickel alloy pipe are given in Table X1.1.

TABLE X1.1 Suggested Wall Thicknesses of Welded Pipe Based on SPS Diameters

SPS, in.	Outside Diameter, in. (mm)	Wall Thickness, in. (mm)		
		A	B	C
2.5	2.875 (73.0)	...	0.083 (2.11)	0.134 (3.40)
3	3.500 (88.9)	...	0.095 (2.42)	0.165 (4.19)
3.5	4.000 (102)	...	0.095 (2.42)	0.180 (4.57)
4	4.500 (114)	...	0.109 (2.77)	0.203 (5.15)
4.5	5.000 (127)	...	0.120 (3.05)	0.203 (5.15)
5	5.563 (141)	...	0.125 (3.17)	0.220 (5.59)
6	6.625 (168)	...	0.134 (3.40)	0.259 (6.57)
7	7.625 (194)	...	0.134 (3.40)	0.284 (7.21)
8	8.625 (219)	...	0.148 (3.76)	0.340 (8.64)
9	9.625 (244)	...	0.187 (4.75)	0.340 (8.64)
10	10.750 (273)	0.134 (3.40)	0.187 (4.75)	0.380 (9.65)
12	12.750 (324)	0.156 (3.96)	0.250 (6.35)	0.454 (11.5)
14	14.0 (355)	0.165 (4.19)	...	...
16	16.0 (406)	0.165 (4.19)	...	...
18	18.0 (457)	0.180 (4.57)	...	...
20	20.0 (508)	0.180 (4.57)	...	...
24	24.0 (609)	0.180 (4.57)	...	...
30	30.0 (761)	0.250 (6.35)	...	...

X2. METRIC EQUIVALENTS

X2.1 The SI unit for strength properties now shown is in accordance with the International System of Units (SI). The derived SI unit for force is the newton (N), which is defined as that force which when applied to a body having a mass of one kilogram gives it an acceleration of one metre per second squared ($N = \text{kg}\cdot\text{m}/\text{s}^2$). The derived SI unit for pressure or

stress is the newton per square metre (N/m^2), which has been named the pascal (Pa) by the General Conference on Weights and Measures. Since $1 \text{ ksi} = 6\,894\,757 \text{ Pa}$, the metric equivalents are expressed as megapascal (MPa), which is the same as MN/m^2 and N/mm^2 .

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