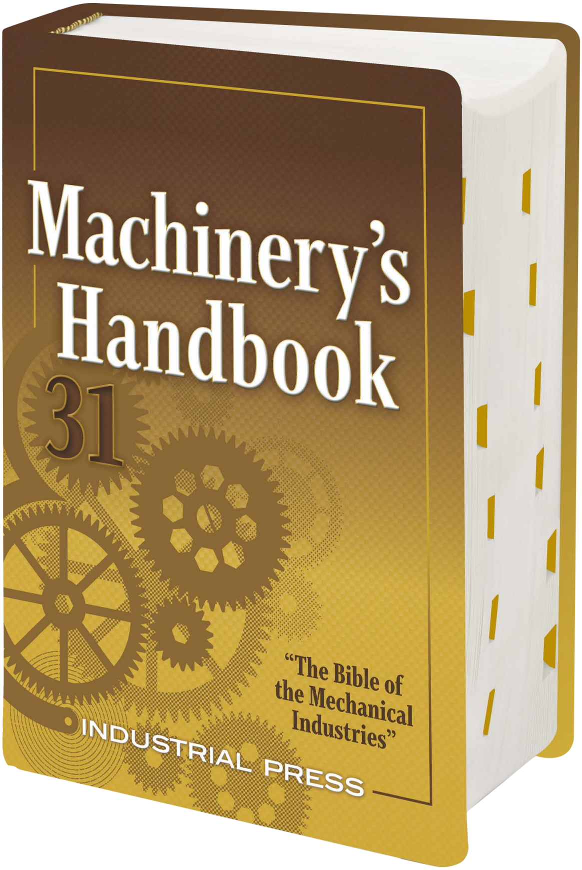
Machinery's Handbook
31
"The Bible of the Mechanical Industries"
INDUSTRIAL PRESS

Machinery's Handbook, 31st Edition

ERRATA (Errors Found Since First Printing)

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Page number for "Simple Interest" corrected to page 144 (was incorrectly page 143).

ENGINEERING ECONOMICS

Cross reference corrected (was incorrectly page 2872).

Acceleration is the time-rate of change of velocity and is expressed as velocity divided by time or as distance divided by time squared, that is, in feet per second per second or feet per second squared (ft/sec^2); inches per second per second or inches per second squared (in/sec^2); centimeters per second per second or centimeters per second squared (cm/sec^2); etc. **The metric SI unit is the meter per second squared (m/sec^2).**

Unit Abbreviations.—Standard abbreviations for the units of physical quantities are used throughout the Handbook. Comprehensive tables of unit abbreviations are found starting on page 2827 for US units, and on page 2832 for metric units.

Unit Systems.—In mechanics calculations, both *absolute* and *gravitational* systems of units are employed. The fundamental quantities in absolute systems are *length*, *time*, and *mass*, and from these the dimension of *force* is derived. Two absolute systems that have been in use for many years are the CGS (centimeter-gram-second) and the MKS (meter-kilogram-second) systems. They are named for the fundamental units of length, mass and time, respectively. Another system known as MKSA (meter-kilogram-second-ampere) links the MKS system of units of mechanics with electromagnetic units.

The General Conference of Weights and Measures (CGPM), which is the body responsible for all international matters concerning the metric system, adopted in 1954 a rationalized and coherent system of units based on the four MKSA units, including the kelvin as the unit of temperature and the candela as the unit of luminous intensity. In 1960, the CGPM formally named this system the "Système International d'Unités," for which the abbreviation is SI in all languages. In 1971, the 14th CGPM adopted a seventh base unit, the *mole,* which is the unit of quantity ("amount of substance"). Further details of the SI are given in the section *MEASURING UNITS* starting on page 2831**, and its application in mechanics calculations, contrasted with the use of the English system, is considered below.**

The fundamental quantities in gravitational systems are *length*, *time*, and *force*, and from these units, the dimension of *mass* is derived. In the gravitational system most widely used in English measure countries, the units of length, time, and force are, respectively, the foot (ft), the second (s or sec), and the pound (lb). The corresponding unit of mass, commonly called the *slug*, is equal to 1 lb-s^2/ft and is derived from the formula, $M = W/g$ in which M = mass in slugs, W = weight in pounds, and g = acceleration due to gravity, commonly taken as 32.16 ft/s^2. A body that weighs 32.16 lbs on the surface of the earth has, therefore, a mass of 1 slug.

Many engineering calculations utilize a system of units consisting of the inch,the second, and the pound. The corresponding units of mass are pounds second squared per inch (lb-s^2/in) and the value of g is taken as 386 in/s^2.

In a gravitational system that has been widely used in metric countries, the units of length, time, and force are, respectively, the meter, the second, and the kilogram-force (1 kgf = 9.80665 N). The corresponding units of mass are kgf-s^2/m and the value of g is taken as 9.81 m/s^2.

Acceleration of Gravity *g* Used in Mechanics Formulas.—The acceleration of a freely falling body varies according to location on the earth's surface as well as the height from which the body falls. Its value measured at sea level at the equator is 32.09 ft/sec^2 while at the poles is 32.26 ft/sec^2. In the United States it is customary to regard 32.16 as satisfactory for most practical purposes in engineering calculations.

Standard Pound Force: For use in defining the magnitude of a standard unit of force, known as the *pound force*, a fixed value of 32.1740 ft/sec^2, designated by the symbol g_0, has been adopted by international agreement. As a result of this agreement, whenever the term mass, M, appears in a mechanics formula and the substitution $M = W/g$ is made, use of the standard value g_0 = 32.1740 ft/sec^2 is implied, although as stated previously, it is customary to use approximate values for g except where extreme accuracy is required.

Adjusting Lengths for Reference Temperature.—The standard reference temperature for industrial length measurements is 20 degrees Celsius (68 degrees Fahrenheit). For other temperatures, corrections should be made in accordance with the difference in thermal expansion for the two parts, especially when the gage is made of a different material than the part to be inspected.

Example: An aluminum part is to be measured with a steel gage when the room temperature is 30 °C. The aluminum part has a coefficient of linear thermal expansion, $\alpha_{Part} = 24.7 \times 10^{-6}$ mm/mm-°C, and for the steel gage, $\alpha_{Gage} = 10.8 \times 10^{-6}$ mm/mm-°C.

At the reference temperature, the specified length of the aluminum part is 20.021 mm. What is the length of the part at the measuring (room) temperature?

ΔL, the change in the measured length due to temperature, is given by:

$$\begin{aligned}\Delta L &= L(T_R - T_0)(\alpha_{Part} - \alpha_{Gage})\\ &= 20.021(30 - 20)(24.7 - 10.8) \times 10^{-6}\text{mm}\\ &= 2782.919 \times 10^{-6} \approx 0.003 \text{ mm}\end{aligned}$$

Page number 373 added to cross references.

where L = length of part at reference temperature; T_R = room temperature (temperature of part and gage) and T_0 = reference temperature.

Thus, the temperature-corrected length at 30°C is $L + \Delta L = 20.021 + 0.003 = 20.024$ mm.

Length Change Due to Temperature.—Table 14 gives changes in length for variations from the standard reference temperature of 68°F (20°C) for materials of known coefficients of expansion, α. Coefficients of expansion are given in tables on pages 372, 373, 374, 386, 387, and elsewhere.

Example: In Table 14, for coefficients between those listed, add appropriate listed values. For example, a length change for a coefficient of 7 is the sum of values in the 5 and 2 columns. Fractional interpolation also is possible. Thus, in a steel bar with a coefficient of thermal expansion of $6.3 \times 10^{-6} = 0.0000063$ in/in = 6.3 µin/in of length/°F, the increase in length at 73°F is 25 + 5 + 1.5 = 31.5 µin/in of length. For a steel with the same coefficient of expansion, the change in length, measured in degrees C, is expressed in microns (micrometers)/meter (µm/m) of length.

Alternatively, and for temperatures beyond the scope of the table, the length difference due to a temperature change is equal to the coefficient of expansion multiplied by the change in temperature, i.e., $\Delta L = \alpha\Delta T$. Thus, for the previous example, $\Delta L = 6.3 \times (73 - 68) = 6.3 \times 5 = 31.5$ µin/in.

Change in Radius of Thin Circular Ring with Temperature.—Consider a circular ring of initial radius r, that undergoes a temperature change ΔT. Initially, the circumference of the ring is $c = 2\pi r$. If the coefficient of expansion of the ring material is α, the change in circumference due to the temperature change is $\Delta c = 2\pi r\,\alpha\Delta T$.

The new circumference of the ring will be: $c_n = c + \Delta c = 2\pi r + 2\pi r\alpha\Delta T = 2\pi r(1 + \alpha\Delta T)$.

Note: An increase in temperature causes Δc to be positive, and a decrease in temperature causes Δc to be negative.

As the circumference increases, the radius of the circle also increases. If the new radius is R, the new circumference is $2\pi R$. For a given change in temperature, ΔT, the change in radius of the ring is found as follows:

$$c_n = 2\pi R = 2\pi r(1 + \alpha\Delta T) \qquad R = r + r\alpha\Delta T \qquad \Delta r = R - r = r\alpha\Delta T$$

Subtitle in parentheses of this table (MH31 pages 423-426) changed (from incorrect subtitle "Hot Rolled, Normalized, and Annealed")

Table 11b. Typical Mechanical Properties of Selected Carbon and Alloy Steels (Quenched-and-Tempered Condition)

AISI No.[a]	Tempering Temperature, °F	Tensile Strength Ultimate (1000 lb/in²)	Tensile Strength Yield (1000 lb/in²)	Elongation, Percent	Reduction in Area, Percent	Hardness, BHN
1030[b]	400	123	94	17	47	495
	600	116	90	19	53	401
	800	106	84	23	60	302
	1000	97	75	28	65	255
	1200	85	64	32	70	207
1040[b]	400	130	96	16	45	514
	600	129	94	18	52	444
	800	122	92	21	57	352
	1000	113	86	23	61	269
	1200	97	72	28	68	201
1040	400	113	86	19	48	262
	600	113	86	20	53	255
	800	110	80	21	54	241
	1000	104	71	26	57	212
	1200	92	63	29	65	192
1050[b]	400	163	117	9	27	514
	600	158	115	13	36	444
	800	145	110	19	48	375
	1000	125	95	23	58	293
	1200	104	78	28	65	235
1050	400	…	…	…	…	…
	600	142	105	14	47	321
	800	136	95	20	50	277
	1000	127	84	23	53	262
	1200	107	68	29	60	223
1060	400	160	113	13	40	321
	600	160	113	13	40	321
	800	156	111	14	41	311
	1000	140	97	17	45	277
	1200	116	76	23	54	229
1080	400	190	142	12	35	388
	600	189	142	12	35	388
	800	187	138	13	36	375
	1000	164	117	16	40	321
	1200	129	87	21	50	255
1095[b]	400	216	152	10	31	601
	600	212	150	11	33	534
	800	199	139	13	35	388
	1000	165	110	15	40	293
	1200	122	85	20	47	235
1095	400	187	120	10	30	401
	600	183	118	10	30	375
	800	176	112	12	32	363
	1000	158	98	15	37	321
	1200	130	80	21	47	269
1137	400	157	136	5	22	352
	600	143	122	10	33	285
	800	127	106	15	48	262
	1000	110	88	24	62	229
	1200	95	70	28	69	197

Parenthetical subtitle corrected.

Table 11b. *(Continued)* **Typical Mechanical Properties of Selected Carbon and Alloy Steels** (Quenched-and-Tempered Condition)

AISI No.[a]	Tempering Temperature, °F	Tensile Strength (1000 lb/in²) Ultimate	Tensile Strength (1000 lb/in²) Yield	Elongation, Percent	Reduction in Area, Percent	Hardness, BHN
1137[b]	400	217	169	5	17	415
	600	199	163	9	25	375
	800	160	143	14	40	311
	1000	120	105	19	60	262
	1200	94	77	25	69	187
1141	400	237	176	6	17	461
	600	212	186	9	32	415
	800	169	150	12	47	331
	1000	130	111	18	57	262
	1200	103	86	23	62	217
1144	400	127	91	17	36	277
	600	126	90	17	40	262
	800	123	88	18	42	248
	1000	117	83	20	46	235
	1200	105	73	23	55	217
1330[b]	400	232	211	9	39	459
	600	207	186	9	44	402
	800	168	150	15	53	335
	1000	127	112	18	60	263
	1200	106	83	23	63	216
1340	400	262	231	11	35	505
	600	230	206	12	43	453
	800	183	167	14	51	375
	1000	140	120	17	58	295
	1200	116	90	22	66	252
4037	400	149	110	6	38	310
	600	138	111	14	53	295
	800	127	106	20	60	270
	1000	115	95	23	63	247
	1200	101	61	29	60	220
4042	400	261	241	12	37	516
	600	234	211	13	42	455
	800	187	170	15	51	380
	1000	143	128	20	59	300
	1200	115	100	28	66	238
4130[b]	400	236	212	10	41	467
	600	217	200	11	43	435
	800	186	173	13	49	380
	1000	150	132	17	57	315
	1200	118	102	22	64	245
4140	400	257	238	8	38	510
	600	225	208	9	43	445
	800	181	165	13	49	370
	1000	138	121	18	58	285
	1200	110	95	22	63	230
4150	400	280	250	10	39	530
	600	256	231	10	40	495
	800	220	200	12	45	440
	1000	175	160	15	52	370
	1200	139	122	19	60	290
4340	400	272	243	10	38	520
	600	250	230	10	40	486
	800	213	198	10	44	430
	1000	170	156	13	51	360
	1200	140	124	19	60	280

Parenthetical subtitle corrected.

Table 11b. *(Continued)* **Typical Mechanical Properties of Selected Carbon and Alloy Steels** (Quenched-and-Tempered Condition)

AISI No.[a]	Tempering Temperature, °F	Tensile Strength Ultimate	Tensile Strength Yield	Elongation, Percent	Reduction in Area, Percent	Hardness, BHN
		1000 lb/in²	1000 lb/in²			
5046	400	253	204	9	25	482
	600	205	168	10	37	401
	800	165	135	13	50	336
	1000	136	111	18	61	282
	1200	114	95	24	66	235
50B46	400	…	…	…	…	560
	600	258	235	10	37	505
	800	202	181	13	47	405
	1000	157	142	17	51	322
	1200	128	115	22	60	273
50B60	400	…	…	…	…	600
	600	273	257	8	32	525
	800	219	201	11	34	435
	1000	163	145	15	38	350
	1200	130	113	19	50	290
5130	400	234	220	10	40	475
	600	217	204	10	46	440
	800	185	175	12	51	379
	1000	150	136	15	56	305
	1200	115	100	20	63	245
5140	400	260	238	9	38	490
	600	229	210	10	43	450
	800	190	170	13	50	365
	1000	145	125	17	58	280
	1200	110	96	25	66	235
5150	400	282	251	5	37	525
	600	252	230	6	40	475
	800	210	190	9	47	410
	1000	163	150	15	54	340
	1200	117	118	20	60	270
5160	400	322	260	4	10	627
	600	290	257	9	30	555
	800	233	212	10	37	461
	1000	169	151	12	47	341
	1200	130	116	20	56	269
51B60	400	…	…	…	…	600
	600	…	…	…	…	540
	800	237	216	11	36	460
	1000	175	160	15	44	355
	1200	140	126	20	47	290
6150	400	280	245	8	38	538
	600	250	228	8	39	483
	800	208	193	10	43	420
	1000	168	155	13	50	345
	1200	137	122	17	58	282
81B45	400	295	250	10	33	550
	600	256	228	8	42	475
	800	204	190	11	48	405
	1000	160	149	16	53	338
	1200	130	115	20	55	280

Parenthetical subtitle corrected.

Table 11b. *(Continued)* **Typical Mechanical Properties of Selected Carbon and Alloy Steels** (Quenched-and-Tempered Condition)

AISI No.[a]	Tempering Temperature, °F	Tensile Strength, Ultimate (1000 lb/in²)	Tensile Strength, Yield (1000 lb/in²)	Elongation, Percent	Reduction in Area, Percent	Hardness, BHN
8630	400	238	218	9	38	465
	600	215	202	10	42	430
	800	185	170	13	47	375
	1000	150	130	17	54	310
	1200	112	100	23	63	240
8640	400	270	242	10	40	505
	600	240	220	10	41	460
	800	200	188	12	45	400
	1000	160	150	16	54	340
	1200	130	116	20	62	280
86B45	400	287	238	9	31	525
	600	246	225	9	40	475
	800	200	191	11	41	395
	1000	160	150	15	49	335
	1200	131	127	19	58	280
8650	400	281	243	10	38	525
	600	250	225	10	40	490
	800	210	192	12	45	420
	1000	170	153	15	51	340
	1200	140	120	20	58	280
8660	400	…	…	…	…	580
	600	…	…	…	…	535
	800	237	225	13	37	460
	1000	190	176	17	46	370
	1200	155	138	20	53	315
8740	400	290	240	10	41	578
	600	249	225	11	46	495
	800	208	197	13	50	415
	1000	175	165	15	55	363
	1200	143	131	20	60	302
9255	400	305	297	1	3	601
	600	281	260	4	10	578
	800	233	216	8	22	477
	1000	182	160	15	32	352
	1200	144	118	20	42	285
9260	400	…	…	…	…	600
	600	…	…	…	…	540
	800	255	218	8	24	470
	1000	192	164	12	30	390
	1200	142	118	20	43	295
94B30	400	250	225	12	46	475
	600	232	206	12	49	445
	800	195	175	13	57	382
	1000	145	135	16	65	307
	1200	120	105	21	69	250

[a] All grades are fine-grained except those in the 1100 series that are coarse-grained. Austenitizing temperatures are given in parentheses. Heat-treated specimens were oil-quenched unless otherwise indicated.

[b] Water quenched.

Source: Bethlehem Steel Corp. and Republic Steel Corp. as published in 1974 DATABOOK issue of the American Society for Metals' *Metal Progress* magazine and used with permission.

Selecting metals with similar electrochemical potentials usually minimizes galvanic corrosion. One method of comparing potentials involves referencing a *galvanic series*. While it should be representative of anticipated environmental conditions, this tool is not used to predict corrosion rates, but rather provides a qualitative evaluation of coupled metal behavior.

To develop a series, a reference half-cell and samples of the target metals are immersed together in an electrolyte solution chosen and circulated to match the expected environmental conditions. Over time, potentials of the target metals are measured relative to the reference half-cell. There are several standard reference half-cell compositions that will yield different values; the appropriate reference is compatible with the electrolyte. A useful standard is ASTM G82-98 (2014), "Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance."

Most published galvanic series data applies to specific flowing seawater environment conditions. While saltwater is highly conductive, freshwater has low conductivity, and dynamic electrolyte conditions will greatly affect potential measurements. Therefore, for critical applications, it is good practice to develop application-specific series data, rather than using published galvanic series information.

For examples of seawater applications, refer to Table 2, which is based on Army Missile Command Report RS-TR-67-11, "Practical Galvanic Series." Materials closer together along the arrow in the series have less corrosion-inducing potential difference between them in that environment. However, use this data with caution in predicting whether corrosion will be a risk. This series indicates which material will be the anode in a couple, though polarity reversals can occur in which a metal normally anodic to another will become cathodic to that same metal. Examples include high-temperature reversals of zinc/iron, aluminum/iron, and aluminum/zinc.

Name corrected (was "Silicone Bronze 655" so "e" removed)

Table 2. Sample Galvanic Series, General Seawater Environment

Active (Anodic)

	Stainless Steel 410 (active)	Stainless Steel 201 (active)
Magnesium	Copper (plated, cast, or wrought)	Carpenter 20 (active)
Mg alloy AZ-31B	Nickel (plated)	Stainless Steel 321 (active)
Mg alloy HK-31A	Chromium (plated)	Stainless Steel 316 (active)
Zinc (hot-dip, die cast, or plated)	Tantalum	Stainless Steel 309 (active)
Beryllium (hot-pressed)	AM350 (active)	Stainless Steel 17-7PH (passive)
Aluminum 7072 clad on 7075	Stainless Steel 310 (active)	Silicon Bronze 655
Aluminum 2014-T3	Stainless Steel 301 (active)	Stainless Steel 304 (passive)
Aluminum 1160-H14	Stainless Steel 304 (active)	Stainless Steel 301 (passive)
Aluminum 7079-T6	Stainless Steel 430 (active)	Stainless Steel 321 (passive)
Cadmium (plated)	Stainless Steel 410 (active)	Stainless Steel 201 (passive)
Uranium	Stainless Steel 17-7PH (active)	Stainless Steel 286 (passive)
Aluminum 218 (die cast)	Tungsten	Stainless Steel 316L (passive)
Aluminum 5052-0	Niobium (columbium) 1% Zr	AM355 (active)
Aluminum 5052-H12	Brass, Yellow, 268	Stainless Steel 202 (passive)
Aluminum 5456-0, H353	Uranium 8% Mo	Carpenter 20 (passive)
Aluminum 5052-H32	Brass, Naval, 464	AM355 (passive)
Aluminum 1100-0	Yellow Brass	A286 (passive)
Aluminum 3003-H25	Muntz Metal 280	Titanium 5A1, 2.5 Sn
Aluminum 6061-T6	Brass (plated)	Titanium 13V, 11Cr, 3Al (annealed)
Aluminum A360 (die cast)	Nickel-Silver (18% Ni)	Titanium 6Al, 4V (solution treated and aged)
Aluminum 7075-T6	Stainless Steel 316L (active)	Titanium 6Al, 4V (anneal)
Aluminum 6061-0	Bronze 220	Titanium 8Mn
Indium	Copper 110	Titanium 13V, 11Cr 3Al (solution heat treated and aged)
Aluminum 2014-0	Red Brass	Titanium 75A
Aluminum 2024-T4	Stainless Steel 347 (active)	AM350 (passive)
Aluminum 5052-H16	Molybdenum (commercial pure)	Silver
Tin (plated)	Copper-Nickel 715	Gold
Stainless Steel 430 (active)	Admiralty Brass	Graphite
Lead	Stainless Steel 202 (active)	
Steel 1010	Bronze, Phosphor 534 (B-1)	
Iron (cast)	Monel 400	

Noble (Cathodic)

Multiple changes made to these 2 tables, particularly to Metric conversions.

Table 2a. Typical Mechanical Properties of Common Plastics (Inch)

Material	Yield Stress, ksi			Elastic Modulus, ksi			Heat Deflection Temperature, °F			Izod Impact Strength, ft lb/in		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
ABS	2.9	6.3	10.7	112.8	333.5	884.5	149	192	244	0.19	4.12	12
PC	5.8	9.1	22.3	261	346.55	870	172	261	369	0.84	16.7	37.4
PEEK	9.425	14.1	16.7	319	568.4	939.6	284	316	500	0.39	1.09	3.18
PET	0.3045	5.6	13.1	130.5	456.75	754	140	159	239	0.26	1.12	1.55
PP	1.2992	3.6	5.1	108.8	195.75	507.5	100	135	239	0.5	4.02	13.5
PP, GF	3.625	8.7	13.1	149.4	609	949.75	140	268	374	0.26	1.8	8.42
PE, HD	1.102	3.1	6.2	65.3	134.415	217.5	100	118	187	0.36	1.44	37.4
PE, LD	1.1165	1.6	9.4	16	33.64	65.105	100	153	214	4.49	8.42	37.4
PMMA	3.625	9.3	12.3	137.8	420.5	549.55	125	193	223	0.22	0.56	2.75
PSU	6.96	12.8	26.8	249.4	817.8	2798.5	175	352	500	0.5	1.42	7.86
PVC	0.21315	2.4	8.6	0.2	313.2	469.8	116	159	189	0.39	11.6	37.4
TS Phenolic	5.945	7.7	8.4	594.5	1015	1252.8	320	349	439	0.39	0.51	0.6
TS Epoxy	0.10005	3.3	12.3	14.5	359.6	870	149	295	649	0.36	0.67	1.29
TS Epoxy, GF	12.035	16.5	21.8	435	2088	2755	329	439	536	0.3	0.54	0.69
TS Polyester	1.45	7.5	17.8	145	584.35	1537	392	486	500	2.3	7.49	17
TS Polyimide	10.585	18.6	23.2	159.5	569.85	1566	356	707	752	0.39	0.66	0.8

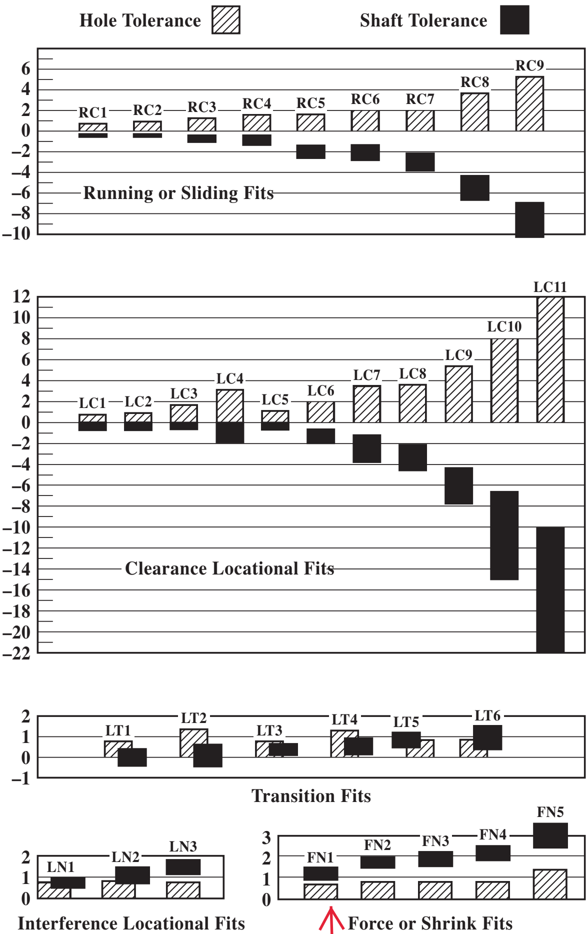
Table 2b. Typical Mechanical Properties of Common Plastics (Metric)

Material	Yield Stress, MPa			Elastic Modulus, GPa			Heat Deflection Temperature, °C			Izod Impact Strength, J/cm		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
ABS	20	43.4	73.5	0.778	2.3	6.1	65	88.9	118	0.1	2.2	6.4
PC	40	62.7	154	1.8	2.39	6	77.8	127	187	0.45	8.92	20
PEEK	65	97.4	115	2.2	3.92	6.48	140	158	260	0.21	0.58	1.7
PET	2.1	38.8	90	0.9	3.15	5.2	60	70.3	115	0.139	0.6	0.83
PP	8.96	25	35.2	0.75	1.35	3.5	37.8	57	115	0.267	2.15	7.2
PP, GF	25	60	90	1.03	4.2	6.55	60	131	190	0.14	0.96	4.5
PE, HD	7.6	21.3	43	0.45	0.927	1.5	37.6	47.5	86.1	0.19	0.77	20
PE, LD	7.7	10.8	64.8	0.11	0.232	0.449	38	67.4	101	2.4	4.5	20
PMMA	25	64	85	0.95	2.9	3.79	51.7	89.4	106	0.12	0.3	1.47
PSU	48	88.1	185	1.72	5.64	19.3	79.4	178	260	0.267	0.76	4.2
PVC	1.47	16.4	59	0.0016	2.16	3.24	46.7	70.8	87.2	0.21	6.2	20
TS Phenolic	41	53.2	57.9	4.1	7	8.64	160	176	226	0.21	0.27	0.32
TS Epoxy	0.69	22.8	85.1	0.1	2.48	6	65	146	343	0.19	0.36	0.69
TS Epoxy, GF	83	114	150	3	14.4	19	165	226	280	0.16	0.29	0.37
TS Polyester	10	51.8	123	1	4.03	10.6	200	252	260	1.23	4	9.08
TS Polyimide	73	128	160	1.1	3.93	10.8	180	375	400	0.21	0.35	0.43

Statistical summary of available grades submitted by material suppliers (data courtesy of MatWeb.com).

The limits for hole and shaft as given in Table 8a to Table 12 are increased for clearance fits (*decreased* for transition or interference fits) by the value of the upper shaft limit, that is, by the amount required to change the maximum shaft to the basic size.

Graphical Representation of ANSI/ASME Standard Limits and Fits
ANSI/ASME B4.1-1967 (2009; out of print)



Diagrams show disposition of hole and shaft tolerances (in thousandths of an inch) with respect to basic size (0) for a diameter of 1 inch.

This figure has been revised per the ANSI/ASME standard.

Change to: *(R2020)*

Table 9b. American National Standard Clearance Locational Fits *ANSI/ASME B4.1-1967 (2009; out of print)*

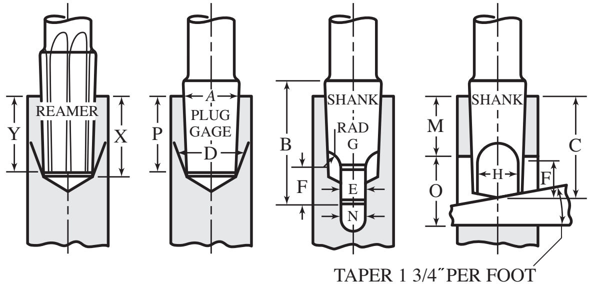
Nominal Size Range, Inches	Class LC 6			Class LC 7			Class LC 8			Class LC 9			Class LC 10			Class LC 11		
	Clearance[a]	Std. Tolerance Limits Hole H9	Std. Tolerance Limits Shaft f8	Clearance[a]	Std. Tolerance Limits Hole H10	Std. Tolerance Limits Shaft e9	Clearance[a]	Std. Tolerance Limits Hole H10	Std. Tolerance Limits Shaft d9	Clearance[a]	Std. Tolerance Limits Hole H11	Std. Tolerance Limits Shaft c10	Clearance[a]	Std. Tolerance Limits Hole H12	Std. Tolerance Limits Shaft	Clearance[a]	Std. Tolerance Limits Hole H13	Std. Tolerance Limits Shaft
Over To	Values shown below are in thousandths of an inch																	
0 - 0.12	0.3 1.9	+1.0 0	−0.3 −0.9	0.6 3.2	+1.6 0	− 0.6 − 1.6	1.0 2.0	+1.6 0	− 1.0 − 2.0	2.5 6.6	+2.5 0	− 2.5 − 4.1	4 12	+4 0	− 4 − 8	5 17	+6 0	− 5 − 11
0.12 – 0.24	0.4 2.3	+1.2 0	−0.4 −1.1	0.8 3.8	+1.8 0	− 0.8 − 2.0	1.2 4.2	+1.8 0	− 1.2 − 2.4	2.8 7.6	+3.0 0	− 2.8 − 4.6	4.5 14.5	+5 0	− 4.5 − 9.5	6 20	+7 0	− 6 −13
0.24 – 0.40	0.5 2.8	+1.4 0	−0.5 −1.4	1.0 4.6	+2.2 0	− 1.0 − 2.4	1.6 5.2	+2.2 0	− 1.6 − 3.0	3.0 8.7	+3.5 0	− 3.0 − 5.2	5 17	+6 0	− 5 −11	7 25	+9 0	− 7 −16
0.40 - 0.71	0.6 3.2	+1.6 0	−0.6 −1.6	1.2 5.6	+2.8 0	− 1.2 − 2.8	2.0 6.4	+2.8 0	− 2.0 − 3.6	3.5 10.3	+4.0 0	− 3.5 − 6.3	6 20	+7 0	− 6 −13	8 28	+10 0	− 8 −18
0.71 - 1.19	0.8 4.0	+2.0 0	−0.8 −2.0	1.6 7.1	+3.5 0	− 1.6 − 3.6	2.5 8.0	+3.5 0	− 2.5 − 4.5	4.5 13.0	+5.0 0	− 4.5 − 8.0	7 23	+8 0	− 7 −15	10 34	+12 0	−10 −22
1.19 - 1.97	1.0 5.1	+2.5 0	−1.0 −2.6	2.0 8.5	+4.0 0	− 2.0 − 4.5	3.6 9.5	+4.0 0	− 3.0 − 5.5	5.0 15.0	+6 0	− 5.0 − 9.0	8 28	+10 0	− 8 −18	12 44	+16 0	−12 −28
1.97 - 3.15	1.2 6.0	+3.0 0	−1.0 −3.0	2.5 10.0	+4.5 0	− 2.5 − 5.5	4.0 11.5	+4.5 0	− 4.0 − 7.0	6.0 17.5	+7 0	− 6.0 −10.5	10 34	+12 0	−10 −22	14 50	+18 0	−14 −32
3.15 - 4.73	1.4 7.1	+3.5 0	−1.4 −3.6	3.0 11.5	+5.0 0	− 3.0 − 6.5	5.0 13.5	+5.0 0	− 5.0 − 8.5	7 21	+9 0	− 7 −12	11 39	+14 0	−11 −25	16 60	+22 0	−16 −38
4.73 - 7.09	1.6 8.1	+4.0 0	−1.6 −4.1	3.5 13.5	+6.0 0	− 3.5 − 7.5	6 16	+6 0	− 6 −10	8 24	+10 0	− 8 −14	12 44	+16 0	−12 −28	18 68	+25 0	−18 −43
7.09 – 9.85	2.0 9.3	+4.5 0	−2.0 −4.8	4.0 15.5	+7.0 0	− 4.0 − 8.5	7 18.5	+7 0	− 7 −11.5	10 29	+12 0	−10 −17	16 52	+18 0	−16 −34	22 78	+28 0	−22 −50
9.85 - 12.41	2.2 10.2	+5.0 0	−2.2 −5.2	4.5 17.5	+8.0 0	− 4.5 − 9.5	7 20	+8 0	− 7 −12	12 32	+12 0	−12 −20	20 60	+20 0	−20 −40	28 88	+30 0	−28 −58
12.41 - 15.75	2.5 12.0	+6.0 0	−2.5 −6.0	5.0 20.0	+9.0 0	− 5 −11	8 23	+9 0	− 8 −14	14 37	+14 0	−14 −23	22 66	+22 0	−22 −44	30 100	+35 0	−30 −65
15.75- 19.69	2.8 12.8	+6.0 0	−2.8 −6.8	5.0 21.0	+10.0 0	− 5 −11	9 25	+10 0	− 9 −15	16 42	+16 0	−16 −26	25 75	+25 0	−25 −50	35 115	+40 0	−35 −75

[a] Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

Limits for sizes above 19.69 inches are not covered by American-British-Canadian (ABC) agreements but are given in the ANSI/ASME Standard.

Change to: -1.2

Table 1a. Morse Stub Taper Shanks



No. of Taper	Taper per Foot[a]	Taper per Inch[b]	Small End of Plug,[b] *D*	Dia. End of Socket,[a] *A*	Shank: Total Length, *B*	Shank: Depth, *C*	Tang: Thickness, *E*	Tang: Length, *F*
1	0.59858	0.049882	0.4314	0.475	1 5/16	1 1/8	13/64	5/16
2	0.59941	0.049951	0.6469	0.700	1 11/16	1 7/16	19/64	7/16
3	0.60235	0.050196	0.8753	0.938	2	1 3/4	25/64	9/16
4	0.62326	0.051938	1.1563	1.231	2 3/8	2 1/16	33/64	11/16
5	0.63151	0.052626	1.6526	1.748	3	2 11/16	3/4	15/16

No. of Taper	Tang: Radius of Mill, *G*	Tang: Diameter, *H*	Socket: Plug Depth, *P*	Socket: Min. Depth of Tapered Hole, Drilled *X*	Socket: Min. Depth of Tapered Hole, Reamed *Y*	Socket: Socket End to Tang Slot, *M*	Tang Slot: Width, *N*	Tang Slot: Length, *O*
1	3/16	13/32	7/8	15/16	29/32	25/32	7/32	23/32
2	7/32	39/64	1 1/16	1 5/32	1 7/64	15/16	5/16	15/16
3	9/32	13/16	1 1/4	1 3/8	1 5/16	1 1/16	13/32	1 1/8
4	3/8	1 3/32	1 7/16	1 9/16	1 1/2	1 3/16	17/32	1 3/8
5	9/16	1 19/32	1 13/16	1 15/16	1 7/8	1 7/16	25/32	1 3/4

All dimensions in inches.

Radius *J* is 3/64, 1/16, 5/64, 3/32, and 1/8 inch respectively for Nos. 1, 2, 3, 4, and 5 tapers.

Corrected to **15/16** (was incorrectly **5/16**)

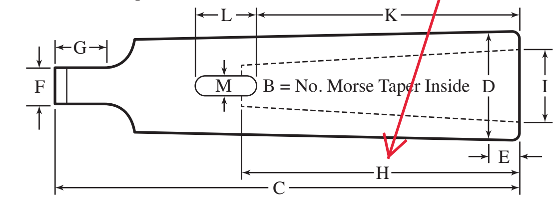
[a] These are basic dimensions.

[b] These dimensions are calculated for reference only.

Jarno Taper.—The Jarno taper was originally proposed by Oscar J. Beale of the Brown & Sharpe Mfg. Co. This taper is based on such simple formulas that practically no calculations are required when the number of taper is known. The taper per foot of all Jarno taper sizes is 0.600 inch on the diameter. The diameter at the large end is as many eighths, the diameter at the small end is as many tenths, and the length as many half inches as are indicated by the number of the taper. For example, a No. 7 Jarno taper is $\frac{7}{8}$ inch in diameter at the large end; $\frac{7}{10}$, or 0.700 inch at the small end; and $\frac{7}{2}$, or $3\frac{1}{2}$ inches long; hence, diameter at large end = No. of taper ÷ 8; diameter at small end = No. of taper ÷ 10; length of taper = No. of taper ÷ 2. The Jarno taper is used on various machine tools, especially profiling machines and die-sinking machines. It has also been used for the headstock and tailstock spindles of some lathes.

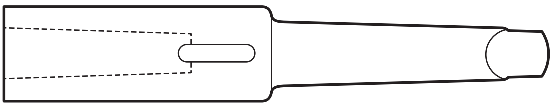
Letter in figure corrected to **H** (was incorrectly **B**).

Table 8. Dimensions of Morse Taper Sleeves



A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*K*	*L*	*M*
2	1	3 9/16	0.700	5/8	1/4	7/16	2 3/16	0.475	2 1/16	3/4	0.213
3	1	3 15/16	0.938	1/4	5/16	9/16	2 3/16	0.475	2 1/16	3/4	0.213
3	2	4 7/16	0.938	3/4	5/16	9/16	2 5/8	0.700	2 1/2	7/8	0.260
4	1	4 7/8	1.231	1/4	15/32	5/8	2 3/16	0.475	2 1/16	3/4	0.213
4	2	4 7/8	1.231	1/4	15/32	5/8	2 5/8	0.700	2 1/2	7/8	0.260
4	3	5 3/8	1.231	3/4	15/32	5/8	3 1/4	0.938	3 1/16	1 3/16	0.322
5	1	6 1/8	1.748	1/4	5/8	3/4	2 3/16	0.475	2 1/16	3/4	0.213
5	2	6 1/8	1.748	1/4	5/8	3/4	2 5/8	0.700	2 1/2	7/8	0.260
5	3	6 1/8	1.748	1/4	5/8	3/4	3 1/4	0.938	3 1/16	1 3/16	0.322
5	4	6 5/8	1.748	3/4	5/8	3/4	4 1/8	1.231	3 7/8	1 1/4	0.478
6	1	8 5/8	2.494	3/8	3/4	1 1/8	2 3/16	0.475	2 1/16	3/4	0.213
6	2	8 5/8	2.494	3/8	3/4	1 1/8	2 5/8	0.700	2 1/2	7/8	0.260
6	3	8 5/8	2.494	3/8	3/4	1 1/8	3 1/4	0.938	3 1/16	1 3/16	0.322
6	4	8 5/8	2.494	3/8	3/4	1 1/8	4 1/8	1.231	3 7/8	1 1/4	0.478
6	5	8 5/8	2.494	3/8	3/4	1 1/8	5 1/4	1.748	4 15/16	1 1/2	0.635
7	3	11 5/8	3.270	3/8	1 1/8	1 3/8	3 1/4	0.938	3 1/16	1 3/16	0.322
7	4	11 5/8	3.270	3/8	1 1/8	1 3/8	4 1/8	1.231	3 7/8	1 1/4	0.478
7	5	11 5/8	3.270	3/8	1 1/8	1 3/8	5 1/4	1.748	4 15/16	1 1/2	0.635
7	6	12 1/2	3.270	1 1/4	1 1/8	1 3/8	7 3/8	2.494	7	1 3/4	0.760

Table 9. Morse Taper Sockets — Hole and Shank Sizes



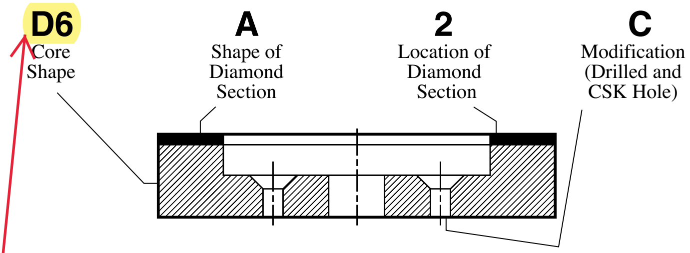
Size	Morse Taper		Size	Morse Taper		Size	Morse Taper	
	Hole	Shank		Hole	Shank		Hole	Shank
1 by 2	No. 1	No. 2	2 by 5	No. 2	No. 5	4 by 4	No. 4	No. 4
1 by 3	No. 1	No. 3	3 by 2	No. 3	No. 2	4 by 5	No. 4	No. 5
1 by 4	No. 1	No. 4	3 by 3	No. 3	No. 3	4 by 6	No. 4	No. 6
1 by 5	No. 1	No. 5	3 by 4	No. 3	No. 4	5 by 4	No. 5	No. 4
2 by 3	No. 2	No. 3	3 by 5	No. 3	No. 5	5 by 5	No. 5	No. 5
2 by 4	No. 2	No. 4	4 by 3	No. 4	No. 3	5 by 6	No. 5	No. 6

Diamond Wheels

Diamond Wheels.—A diamond wheel is a special type of grinding wheel in which the abrasive elements are diamond grains held in a bond and applied to form a layer on the operating face of a non-abrasive core. Diamond wheels are used for grinding very hard or highly abrasive materials. Primary applications are the grinding of cemented carbides, such as the sharpening of carbide cutting tools; the grinding of glass, ceramics, asbestos, and cement products; and the cutting and slicing of germanium and silicon.

Shapes of Diamond Wheels.—The industry-wide accepted Standard (ANSI B74.3-2003 (R2014) specifies ten basic diamond wheel core shapes which are shown in Table 1 with the applicable designation symbols. The applied diamond abrasive layer may have different cross-sectional shapes. Those standardized are shown in Table 2. The third aspect which is standardized is the location of the diamond section on the wheel as shown by the diagrams in Table 3. Finally, modifications of the general core shape together with pertinent designation letters are given in Table 4.

The characteristics of the wheel shape listed in these four tables make up the components of the standard designation symbol for diamond wheel shapes. An example of that symbol with arbitrarily selected components is shown in Fig. 1.



Instead of **D6**, per standard ANSI B74.3-2003 (R2014) page 2, this should be just: **6**

Fig. 1. A Typical Diamond Wheel Shape Designation Symbol

An explanation of these components is as follows:

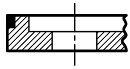
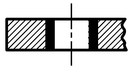
Basic Core Shape: This portion of the symbol indicates the basic shape of the core on which the diamond abrasive section is mounted. The shape is actually designated by a number. The various core shapes and their designations are given in Table 1.

Diamond Cross-Sectional Shape: This, the second component, consisting of one or two letters, denotes the cross-sectional shape of the diamond abrasive section. The various shapes and their corresponding letter designations are given in Table 2.

Diamond Section Location: The third component of the symbol consists of a number which gives the location of the diamond section, i.e., periphery, side, corner, etc. An explanation of these numbers is shown in Table 3.

Modification: The fourth component of the symbol is a letter designating some modification, such as drilled and counterbored holes for mounting or special relieving of diamond section or core. This modification position of the symbol is used only when required. The modifications and their designations are given in Table 4.

Table 3. *(Continued)* **Designations for Location of Diamond Section on Diamond Wheel** *ANSI B74.3-2003 (R2014)*

Designation No. and Location	Description	Illustration
9 — Corner	Designates a location which would commonly be considered to be on the periphery except that the diamond section shall be on the corner but shall not extend to the other corner.	
10 — Annular	Designates a location of the diamond abrasive section on the inner annular surface of the wheel.	

Composition of Diamond and Cubic Boron Nitride Wheels.—According to American National Standard ANSI B74.13-2016, a series of symbols is used to designate the composition of these wheels. An example is shown below.

Prefix	Abrasive	Grain Size	Grade	Concentration	Bond Type	Bond Modification	Depth of Abrasive	Manufacturer's Identification Symbol
M	D	120	R	100	B	56	$\frac{1}{8}$	*

Per standard ANSI B74.13-2016, page 3, **R** should be **N**

Fig. 2. Designation Symbols for Composition of Diamond and Cubic Boron Nitride Wheels

The meaning of each symbol is indicated by the following list:

1) *Prefix:* The prefix is a manufacturer's symbol indicating the exact kind of abrasive. Its use is optional.

2) *Abrasive Type:* The letter (B) is used for cubic boron nitride and (D) for diamond.

3) *Grain Size:* The grain sizes commonly used and varying from coarse to very fine are indicated by the following numbers: 8, 10, 12, 14, 16, 20, 24, 30, 36, 46, 54, 60, 70, 80, 90, 100, 120, 150, 180, and 220. The following additional sizes are used occasionally: 240, 280, 320, 400, 500, and 600. The wheel manufacturer may add to the regular grain number an additional symbol to indicate a special grain combination.

4) *Grade:* Grades are indicated by letters of the alphabet from A to Z in all bonds or processes. Wheel grades from A to Z range from soft to hard.

5) *Concentration:* The concentration symbol is a manufacturer's designation. It may be a number or a symbol.

6) *Bond:* Bonds are indicated by the following letters: B, resinoid; V, vitrified; M, metal.

7) *Bond Modification:* Within each bond type a manufacturer may have modifications to tailor the bond to a specific application. These modifications may be identified by either letters or numbers.

8) *Abrasive Depth:* Abrasive section depth, in inches or millimeters (inches illustrated), is indicated by a number or letter which is the amount of total dimensional wear a user may expect from the abrasive portion of the product. Most diamond and CBN wheels are made with a depth of coating on the order of $\frac{1}{16}$ in., $\frac{1}{8}$ in., (1.6 mm, 3.2 mm) or more as specified. In some cases the diamond is applied in thinner layers, as thin as one thickness of diamond grains. The L is included in the marking system to identify a layered type product.

9) *Manufacturer's Identification Symbol:* The use of this symbol is optional.

reduce wear and prevent galling, corrosion, and seizure of metals. For use on aluminum, copper, steel, stainless steel, titanium, and chromium, and nickel bearing surfaces.

Types I, II, and III have a thicknesses of 0.008 - 0.013 mm. No single reading less than 0.005 mm or greater than 0.018 mm.

Type I has a curing temperature of 150 ± 15°C and an endurance life of 250 minutes; Type II, 204 ± 15°C and 450 minutes; and Type III is a low volatile organic compound (VOC) content lubricant with cure cycles of 150 ± 15°C for 2 hours, or 204 ± 15°C for 1 hour with an endurance life of 450 minutes. Color 1 has a natural product color and Color 2 has a black color.

Nickel, QQ-N-290A: There is a nickel finish for almost any need. Nickel can be deposited soft, hard-dull, or bright, depending on process used and conditions employed in plating. Thus, hardness can range from 150–500 HV (Vickers). Nickel can be similar to stainless steel in color, or can be a dull gray (almost white) color. Corrosion resistance is a function of thickness. Nickel has a low coefficient of thermal expansion. All steel parts having a tensile strength of 220,000 or greater shall not be a nickel plate without specific approval of procuring agency.

Class 1 is used for corrosion protection. Plating shall be app[illegible] copper or yellow brass on zinc and zinc based alloys. In no c[illegible] plate be substituted for any part of the specified nickel thick[illegible] neering applications.

.0002 in. (5.08 µm).

Grade A has a thickness of 0.0016 inch (41 µm); Grade B, 0.0012 in. (30.48 µm); Grade C, 0.001 in. (25.4 µm); Grade D, 0.0008 in. (20.32 µm); Grade E, 0.0006 in. (15.24 µm); Grade F, 0.0004 in. (10.16 µm); and Grade G, 0.002 in (50.8 µm).

Palladium, MIL-P-45209B: A gray, dense deposit good for undercoats. Has good wear characteristics, corrosion resistance, catalytic properties, and good conductivity. The thickness shall be 0.00005 in. (1.27 µm) unless otherwise specified.

Steel springs and other steel parts subject to flexure or repeated impact and of hardness greater than 40 RC are heated to 375 ± 25°F (190 ± 14°C) for 3 hours after plating.

Chemical Passivation, ASTM A967: This process aims to improve the corrosion resistance of parts by removing contaminants from surfaces and facilitating formation of a passive oxide layer. Commercial passivation is performed on austenitic, ferritic, and martensitic stainless steels of the 200, 300, and 400 series, and related variants such as precipitation-hardening stainless steels.

Passivation methods included in the standard are nitric acid immersion, citric acid immersion, and electrochemical treatment (See *Electropolishing, ASTM B912-02 (2018)* on page 1644). Nitric acid has long been used for chemical passivation, but safety and environmental concerns have led to the increasing use of citric acid, when possible. Various grades of stainless steel respond to passivation and related chemistry differently, so care must be taken when specifying a process.

The efficacy of chemical passivation depends on the amount of dynamic contact between the fluid and critical part surfaces. For parts with complex geometry, deep bores, or blind holes, the process may require agitation, repositioning, and use of fixtures.

Phosphate Coating: Light, TT-C-490D: This specification covers cleaning methods and pretreatment processes.

Methods / Types	Typical Thickness (in.)	Comments
Cleaning Methods		
	…	Light coating for use as a paint base.
Method I	…	Mechanical or abrasive cleaning (for ferrous surfaces only).
Method II	…	Used for solvent cleaning.
Method III	…	Used for hot alkalines (for ferrous surfaces only).
Method IV	…	Emulsion.
Method V	…	Used for alkaline derusting (for ferrous surfaces only).
Method VI	…	Phosphoric acid.

Screw, SAE Grade 8 Steel; and (3) .75 × 5.00 Hex Lag Screw, Steel. (4) ½-13 Square Nut, Steel, Zinc Plated; (5) ¾-16 Heavy Hex Nut, SAE J995 Grade 5 Steel; and (6) 1000-8 Hex Thick Slotted Nut, ASTM F594 (Alloy Group 1) Corrosion-Resistant Steel.

Table 1. American National Standard and Unified Standard Square Bolts
ANSI/ASME B18.2.1-2012

SQUARE BOLTS (Fig. 1)											
Nominal Size[a] or Basic Product Dia.		Body Dia.[b] *E*	Width Across Flats *F*			Width Across Corners *G*		Head Height *H*			Thread Length[c] *L_T*
		Max.	Basic	Max.	Min.	Max.	Min.	Basic	Max.	Min.	Nom.
¼	0.2500	0.260	⅜	0.375	0.362	0.530	0.498	11/64	0.188	0.156	0.750
5/16	0.3125	0.324	½	0.500	0.484	0.707	0.665	13/64	0.220	0.186	0.875
⅜	0.3750	0.388	9/16	0.562	0.544	0.795	0.747	¼	0.268	0.232	1.000
7/16	0.4375	0.452	⅝	0.625	0.603	0.884	0.828	19/64	0.316	0.278	1.125
½	0.5000	0.515	¾	0.750	0.725	1.061	0.995	21/64	0.348	0.308	1.250
⅝	0.6250	0.642	15/16	0.938	0.906	1.326	1.244	27/64	0.444	0.400	1.500
¾	0.7500	0.768	1⅛	1.125	1.088	1.591	1.494	½	0.524	0.476	1.750
⅞	0.8750	0.895	1 5/16	1.312	1.269	1.856	1.742	19/32	0.620	0.568	2.000
1	1.0000	1.022	1½	1.500	1.450	2.121	1.991	21/32	0.684	0.628	2.250
1⅛	1.1250	1.149	1 11/16	1.688	1.631	2.386	2.239	¾	0.780	0.720	2.500
1¼	1.2500	1.277	1⅞	1.875	1.812	2.652	2.489	27/32	0.876	0.812	2.750
1⅜	1.3750	1.404	2 1/16	2.602	1.994	2.917	2.738	29/32	0.940	0.872	3.000
1½	1.5000	1.531	2¼	2.250	2.175	3.182	2.986	1	1.036	0.964	3.250

2.062

[a] Where specifying nominal size in decimals, zeros before the decimal point and in the fourth decimal place are omitted.

[b] See *Body Diameter* footnote in Table 3.

[c] Thread lengths, L_T, shown are for bolt lengths 6 inches and shorter. For longer bolt lengths add 0.250 inch to thread lengths shown.

Table 2. American National Standard Heavy Hex Structural Bolts
ANSI/ASME B18.2.1-1981 (R1992)[a]

HEAVY HEX STRUCTURAL BOLTS (Fig. 2)													
Nominal Size[a] or Basic Product Dia.		Body Dia. *E*		Width Across Flats *F*		Width Across Corners *G*		Height *H*		Radius of Fillet *R*		Thread Length L_T	Trans. Thread *Y*
		Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Basic	Max.
½	0.5000	0.515	0.482	0.875	0.850	1.010	0.969	0.323	0.302	0.031	0.009	1.00	0.19
⅝	0.6250	0.642	0.605	1.062	1.031	1.227	1.175	0.403	0.378	0.062	0.021	1.25	0.22
¾	0.7500	0.768	0.729	1.250	1.212	1.443	1.383	0.483	0.455	0.062	0.021	1.38	0.25
⅞	0.8750	0.895	0.852	1.438	1.394	1.660	1.589	0.563	0.531	0.062	0.031	1.50	0.28
1	1.0000	1.022	0.976	1.625	1.575	1.876	1.796	0.627	0.591	0.093	0.062	1.75	0.31
1⅛	1.1250	1.149	1.098	1.812	1.756	2.093	2.002	0.718	0.658	0.093	0.062	2.00	0.34
1¼	1.2500	1.277	1.223	2.000	1.938	2.309	2.209	0.813	0.749	0.093	0.062	2.00	0.38
1⅜	1.3750	1.404	1.345	2.188	2.119	2.526	2.416	0.878	0.810	0.093	0.062	2.25	0.44
1½	1.5000	1.531	1.470	2.375	2.300	2.742	2.622	0.974	0.902	0.093	0.062	2.25	0.44

[a] The table has been included for reference only. Heavy hex structural bolts have been removed from ANSI/ASME B18.2.1 and are now included in ANSI/ASME B18.2.6.

All dimensions are in inches. **Bold type shows bolts unified dimensionally with British and Canadian Standards.** Threads, when rolled, shall be Unified Coarse, Fine, or 8-thread series (UNRC, UNRF, or 8 UNR Series), Class 2A. Threads produced by other methods may be Unified Coarse, Fine, or 8-thread series (UNC, UNF, or 8 UN Series), Class 2A.

Table 4. American National Standard and Unified Standard Heavy Hex Screws and Hex Cap Screws *ANSI/ASME B18.2.1-2012*

Nominal Size[a] or Basic Product Dia.		Body Dia. *E*		Width Across Flats *F*			Width Across Corners *G*		Height *H*			Thread Length[b] L_T
		Max.	Min.	Basic	Max.	Min.	Max.	Min.	Basic	Max.	Min.	Basic
HEAVY HEX SCREWS (Fig. 4)												
3/8	0.3750	0.3750	0.360	11/16	0.688	0.669	0.794	0.763	15/64	0.243	0.226	1.000
1/2	0.5000	0.5000	0.482	7/8	0.875	0.850	1.010	0.969	5/16	0.323	0.302	1.250
5/8	0.6250	0.6250	0.605	1 1/16	1.062	1.031	1.227	1.175	25/64	0.403	0.378	1.500
3/4	0.7500	0.7500	0.729	1 1/4	1.250	1.212	1.443	1.383	15/32	0.483	0.455	1.750
7/8	0.8750	0.8750	0.852	1 7/16	1.438	1.394	1.660	1.589	35/64	0.563	0.531	2.000
1	1.0000	1.0000	0.976	1 5/8	1.625	1.575	1.876	1.796	39/64	0.627	0.591	2.250
1 1/8	1.1250	1.1250	1.098	1 13/16	1.812	1.756	2.093	2.002	11/16	0.718	0.658	2.500
1 1/4	1.2500	1.2500	1.223	2	2.000	1.938	2.309	2.209	25/32	0.813	0.749	2.750
1 3/8	1.3750	1.3750	1.345	2 3/16	2.188	2.119	2.526	2.416	27/32	0.878	0.810	3.000
1 1/2	1.5000	1.5000	1.470	2 5/8	2.375	2.300	2.742	2.622	15/16	0.974	0.902	3.250
1 5/8	1.6250	1.6250	1.591	2 9/16	2.562	2.481	2.959	2.829	1	1.038	0.962	3.500
1 3/4	1.7500	1.7500	1.716	2 3/4	2.750	2.662	3.175	3.035	1 3/32	1.134	1.054	3.750
1 7/8	1.8750	1.8750	1.839	2 15/16	2.938	2.844	3.392	3.242	1 5/32	1.198	1.114	4.000
2	2.0000	2.0000	1.964	3 1/8	3.125	3.025	3.608	3.449	1 7/32	1.263	1.175	4.250
2 1/4	2.2500	2.2500	2.214	3 1/2	3.500	3.388	4.041	3.862	1 3/8	1.423	1.327	5.000[c]
2 1/2	2.5000	2.5000	2.461	3 7/8	3.875	3.750	4.474	4.275	1 17/32	1.583	1.479	5.500[c]
2 3/4	2.7500	2.7500	2.711	4 1/4	4.250	41.112	4.907	4.688	1 11/16	1.744	1.632	6.000[c]
3	3.0000	3.0000	2.961	4 5/8	4.625	4.475	5.340	5.102	1 7/8	1.935	1.815	6.500[c]
3 1/4	3.2500	3.2500	3.210	5	5.000	4.838	5.774	5.515	2	2.126	1.998	7.000[c]
3 1/2	3.5000	3.5000	3.461	5 3/8	5.375	5.200	6.207	5.928	2 1/4	2.256	2.120	7.500[c]
3 3/4	3.7500	3.7500	3.711	5 3/4	5.750	5.562	6.640	6.341	2 3/8	2.447	2.303	8.000[c]
4	4.0000	4.0000	3.961	6 1/8	6.125	5.925	7.073	6.755	2 1/2	2.576	2.424	8.500[c]
4 1/4	4.2500	4.2500	4.223	6 1/2	6.500	6.288	7.506	7.168	2 3/4	2.768	2.608	9.000[c]
4 1/2	4.5000	4.5000	4.473	6 7/8	6.875	6.650	7.939	7.581	2 7/8	2.896	2.728	9.500[c]
4 3/4	4.7500	4.7500	4.723	7 1/4	7.250	7.012	8.372	7.994	3	3.088	2.912	10.000[c]
5	5.0000	5.0000	4.973	7 5/8	7.625	7.375	8.805	8.408	3 1/8	3.217	3.033	10.500[c]
5 1/4	5.2500	5.2500	5.223	8	8.000	7.738	9.238	8.821	3 3/8	3.408	3.216	11.000[c]
5 1/2	5.5000	5.5000	5.473	8 3/8	8.375	8.100	9.671	9.234	3 1/2	3.538	3.338	11.500[c]
5 3/4	5.7500	5.7500	5.723	8 3/4	8.750	8.462	10.104	9.647	3 5/8	3.729	3.521	12.000[c]
6	6.0000	6.0000	5.973	9 1/8	9.125	8.825	10.537	10.060	3 3/4	3.858	3.642	12.500[c]
HEX CAP SCREWS (Finished Hex Bolts) (Fig. 4)												
1/4	0.2500	0.2500	0.2450	7/16	0.438	0.428	0.505	0.488	5/32	0.163	0.150	0.750
5/16	0.3125	0.3125	0.3065	1/2	0.500	0.489	0.577	0.557	13/64	0.211	0.195	0.875
3/8	0.3750	0.3750	0.3690	9/16	0.562	0.551	0.650	0.628	15/64	0.243	0.226	1.000
7/16	0.4375	0.4375	0.4305	5/8	0.625	0.612	0.722	0.698	9/32	0.291	0.272	1.125
1/2	0.5000	0.5000	0.4930	3/4	0.750	0.736	0.866	0.840	5/16	0.323	0.302	1.250
9/16	0.5625	0.5625	0.5545	13/16	0.812	0.798	0.938	0.910	23/64	0.371	0.348	1.375
5/8	0.6250	0.6250	0.6170	15/16	0.938	0.922	1.083	1.051	25/64	0.403	0.378	1.500
3/4	0.7500	0.7500	0.7410	1 1/8	1.125	1.100	1.299	1.254	15/32	0.483	0.455	1.750
7/8	0.8750	0.8750	0.8660	1 5/16	1.312	1.285	1.516	1.465	35/64	0.563	0.531	2.000
1	1.0000	1.0000	0.9900	1 1/2	1.500	1.469	1.732	1.675	39/64	0.627	0.591	2.250
1 1/8	1.1250	1.1250	1.1140	1 11/16	1.688	1.631	1.949	1.859	11/16	0.718	0.658	2.500
1 1/4	1.2500	1.2500	1.2390	1 7/8	1.875	1.812	2.165	2.066	25/32	0.813	0.749	2.750
1 3/8	1.3750	1.3750	1.3630	2 1/16	2.062	1.994	2.382	2.273	27/32	0.878	0.810	3.000
1 1/2	1.5000	1.5000	1.4880	2 1/4	2.250	2.175	2.598	2.480	15/16	0.974	0.902	3.250
1 5/8	1.6250	1.6250	1.6130	2 7/16	2.438	2.356	2.815	2.686	1	1.038	0.962	3.500
1 3/4	1.7500	1.7500	1.7380	2 5/8	2.625	2.538	3.031	2.893	1 3/32	1.134	1.054	3.750
1 7/8	1.8750	1.8750	1.8630	2 13/16	2.812	2.719	3.248	3.099	1 5/32	1.198	1.114	4.000
2	2.0000	2.0000	1.9880	3	3.000	2.900	3.464	3.306	1 7/32	1.263	1.175	4.250
2 1/4	2.2500	2.2500	2.2380	3 3/8	3.375	3.262	3.897	3.719	1 3/8	1.423	1.327	5.000[c]
2 1/2	2.5000	2.5000	2.4880	3 3/4	3.750	3.625	4.330	4.133	1 17/32	1.583	1.479	5.500[c]
2 3/4	2.7500	2.7500	2.7380	4 1/8	4.125	3.988	4.763	4.546	1 11/16	1.744	1.632	6.000[c]
3	3.0000	3.0000	2.9880	4 1/2	4.500	4.350	5.196	4.959	1 7/8	1.935	1.815	6.500[c]

6.0000 6.0000 corrected (previously incorrectly read 5.0000 5.0000).

[a] *Nominal Size:* Where specifying nominal size in decimals, zeros preceding the decimal and in the fourth decimal place are omitted.

[b] Thread lengths, L_T, shown are for bolt lengths 6 inches and shorter. For longer bolt lengths add 0.250 inch to thread lengths shown.

[c] Thread lengths, L_T, shown are for bolt lengths over 6 inches.

All dimensions are in inches.

Unification: **Bold type indicates product features unified dimensionally with British and Canadian Standards.** Unification of fine thread products is limited to sizes 1 inch and smaller.

Bearing Surface: Bearing surface is flat and washer faced. Diameter of bearing surface is equal to the maximum width across flats within a tolerance of minus 10 percent.

Threads Series: Threads, when rolled, are Unified Coarse, Fine, or 8-thread series (UNRC, UNRF, or 8 UNR Series), Class 2A. Threads produced by other methods shall preferably be UNRC, UNRF or 8 UNR but, at manufacturer's option, may be Unified Coarse, Fine or 8-thread series (UNC, UNF, or 8 UN Series), Class 2A.

Material: Chemical and mechanical properties of steel screws normally conform to Grades 2, 5, or 8 of SAE J429, ASTM A449 or ASTM A354 Grade BD. Where specified, screws may also be made from brass, bronze, corrosion-resisting steel, aluminum alloy or other materials.

Table 1. Wrench Openings for Nuts *ANSI/ASME B18.2.2-2015, Appendix*

Max.[a] Width Across Flats of Nut	Wrench Opening[b] Min.	Wrench Opening[b] Max.	Max.[a] Width Across Flats of Nut	Wrench Opening[b] Min.	Wrench Opening[b] Max.	Max.[a] Width Across Flats of Nut	Wrench Opening[b] Min.	Wrench Opening[b] Max.
5/32	0.158	0.163	1 1/4	1.257	1.267	2 15/16	2.954	2.973
3/16	0.190	0.195	1 5/16	1.320	1.331	*3*	*3.016*	*3.035*
7/32	0.220	0.225	*1 3/8*	*1.383*	*1.394*	3 1/8	3.142	3.162
1/4	0.252	0.257	1 7/16	1.446	1.457	*3 3/8*	*3.393*	*3.414*
9/32	0.283	0.288	1 1/2	1.508	1.520	3 1/2	3.518	3.540
5/16	0.316	0.322	1 5/8	1.634	1.646	*3 3/4*	*3.770*	*3.793*
11/32	0.347	0.353	1 11/16	1.696	1.708	3 7/8	3.895	3.918
3/8	0.378	0.384	1 13/16	1.822	1.835	*4 1/8*	*4.147*	*4.172*
7/16	0.440	0.446	1 7/8	1.885	1.898	4 1/4	4.272	4.297
1/2	0.504	0.510	2	2.011	2.025	4 1/2	4.524	4.550
9/16	0.566	0.573	2 1/16	2.074	2.088	4 5/8	4.649	4.676
5/8	0.629	0.636	2 3/16	2.200	2.215	*4 7/8*	*4.900*	*4.928*
11/16	0.692	0.699	2 1/4	2.262	2.277	5	5.026	5.055
3/4	0.755	0.763	2 3/8	2.388	2.404	*5 1/4*	*5.277*	*5.307*
13/16	0.818	0.826	*2 7/16*	*2.450*	*2.466*	5 3/8	5.403	5.434
7/8	0.880	0.888	2 9/16	2.576	2.593	*5 5/8*	*5.654*	*5.686*
15/16	0.944	0.953	*2 5/8*	*2.639*	*2.656*	5 3/4	5.780	5.813
1	1.006	1.015	2 3/4	2.766	2.783	*6*	*6.031*	6.157
1 1/16	1.068	1.077	*2 13/16*	*2.827*	*2.845*	6 1/8	6.065	6.192
1 1/8	1.132	1.142						

1 1/16 corrected (1 added; previously was just 1/16).

[a] Wrenches are marked with the "Nominal Size of Wrench," which is equal to the basic or maximum width across flats of the corresponding nut. Minimum wrench opening is (1.005W + 0.001). Tolerance on wrench opening is (0.005W + 0.004) from minimum, where W equals nominal size of wrench.

[b] Openings for 5/32 to 3/8 widths from old ASA B18.2-1960 and italic values are from former ANSI B18.2.2-1972.

All dimensions given in inches.

Table 2. Clearances for Open End Engineers Wrench (15°)

Nominal Wrench Size		*A* Min. (in.)	*B*[a] Max. (in.)	*C* Min. (in.)	*D* Min. (in.)	*E* Min. (in.)	*F*[b] Max. (in.)	*G* Ref. (in.)	*H*[c] Max. (in.)	*J* Min.[d] in.-lbf
5/32	0.156	0.220	0.250	0.390	0.160	0.250	0.200	0.030	0.094	35
3/16	0.188	0.250	0.280	0.430	0.190	0.270	0.230	0.030	0.172	45
1/4	0.250	0.280	0.340	0.530	0.270	0.310	0.310	0.030	0.172	67
5/16	0.313	0.380	0.470	0.660	0.280	0.390	0.390	0.050	0.203	138
11/32	0.344	0.420	0.500	0.750	0.340	0.450	0.450	0.050	0.203	193
3/8	0.375	0.420	0.500	0.780	0.360	0.450	0.520	0.050	0.219	275
7/16	0.438	0.470	0.590	0.890	0.420	0.520	0.640	0.050	0.250	413
1/2	0.500	0.520	0.640	1.000	0.470	0.580	0.660	0.050	0.266	550
9/16	0.563	0.590	0.770	1.130	0.520	0.660	0.700	0.050	0.297	770
5/8	0.625	0.640	0.830	1.230	0.550	0.700	0.700	0.050	0.344	1100
11/16	0.688	0.770	0.920	1.470	0.660	0.880	0.800	0.060	0.375	1375
3/4	0.750	0.770	0.920	1.510	0.670	0.880	0.800	0.060	0.375	1650
13/16	0.813	0.910	1.120	1.660	0.720	0.970	0.860	0.060	0.406	2200
7/8	0.875	0.970	1.150	1.810	0.800	1.060	0.910	0.060	0.438	2475
15/16	0.938	0.970	1.150	1.850	0.810	1.060	0.950	0.060	0.438	3025
1	1.000	1.050	1.230	2.000	0.880	1.160	1.060	0.060	0.500	3575
1 1/16	1.063	1.090	1.250	2.100	0.970	1.200	1.200	0.080	0.500	3850
1 1/8	1.125	1.140	1.370	2.210	1.000	1.270	1.230	0.080	0.500	4400
1 1/4	1.250	1.270	1.420	2.440	1.080	1.390	1.310	0.080	0.562	5775
1 5/16	1.313	1.390	1.690	2.630	1.170	1.520	1.340	0.080	0.562	6600
1 7/16	1.438	1.470	1.720	2.800	1.250	1.590	1.340	0.090	0.641	8250
1 1/2	1.500	1.470	1.720	2.840	1.270	1.590	1.450	0.090	0.641	8500
1 5/8	1.625	1.560	1.880	3.100	1.380	1.750	1.560	0.090	0.641	9000

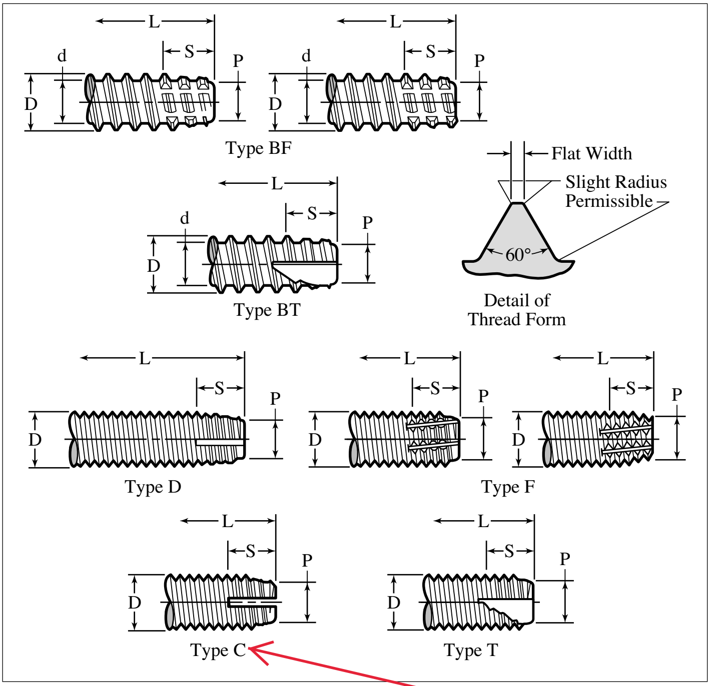
[a] *B* = arc radius created by the swing of the wrench.

[b] *F* = inside arc radius of part.

[c] *H* = thickness of wrench head. (Dimension line not shown.)

[d] *J* = torque that wrench will withstand in inch-pounds. Values updated from ANSI/ASME B107.100-2010, Wrenches.

Table 2. ANSI Standard Threads and Points for Thread Cutting Self-Tapping Screws *ANSI/ASME B18.6.3-2013*



See Table 5 and Table 7 for thread data.

Change to "Type G"

Cross Recesses.—Type I cross recess has a large center opening, tapered bottom, with all edges relieved or rounded. Type IA cross recess has a large center opening, wide straight wings, and blunt bottom, with all edges relieved or rounded. Type II consists of two intersecting slots with parallel sides converging to a slightly truncated apex at the bottom of the recess. Type III has a square center opening, slightly tapered side walls, and a conical bottom, with top edges relieved or rounded.

Table 3. ANSI Standard Cross Recesses for Self-Tapping Screws *ANSI/ASME B18.6.3-2013* **and Metric Thread Forming and Thread Cutting Tapping Screws** *ANSI/ASME B18.6.5M-2000 (Withdrawn)*

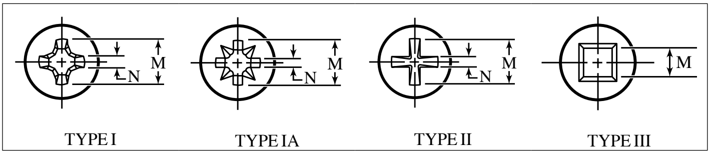


Table 3. *(Continued)* **Standard Series and Selected Combinations—Unified Screw Threads**

Nominal Size, Threads per Inch, and Series Designation[a]	External[b]								Internal[b]					
	Class	Allowance	Major Diameter			Pitch Diameter		UNR Minor Dia.,[c] Max (Ref.)	Class	Minor Diameter		Pitch Diameter		Major Diameter
			Max[d]	Min	Min[e]	Max[d]	Min			Min	Max	Min	Max	Min
7/8-24 UNS	2A	0.0012	0.8738	0.8666	—	0.8467	0.8425	0.8242	2B	0.830	0.840	0.8479	0.8533	0.8750
7/8-27 UNS	2A	0.0012	0.8738	0.8671	—	0.8497	0.8457	0.8297	2B	0.835	0.844	0.8509	0.8561	0.8750
7/8-28 UN	2A	0.0012	0.8738	0.8673	—	0.8506	0.8467	0.8313	2B	0.836	0.845	0.8518	0.8569	0.8750
	3A	0.0000	0.8750	0.8685	—	0.8518	0.8489	0.8325	3B	0.8360	0.8426	0.8518	0.8556	0.8750
7/8-32 UN	2A	0.0011	0.8739	0.8679	—	0.8536	0.8499	0.8367	2B	0.841	0.849	0.8547	0.8595	0.8750
	3A	0.0000	0.8750	0.8690	—	0.8547	0.8519	0.8378	3B	0.8410	0.8469	0.8547	0.8583	0.8750
15/16-12 UN	2A	0.0017	0.9358	0.9244	—	0.8817	0.8761	0.8366	2B	0.847	0.865	0.8834	0.8907	0.9375
	3A	0.0000	0.9375	0.9261	—	0.8834	0.8792	0.8383	3B	0.8470	0.8575	0.8834	0.8889	0.9375
15/16-16 UN	2A	0.0015	0.9360	0.9266	—	0.8954	0.8904	0.8616	2B	0.870	0.884	0.8969	0.9033	0.9375
	3A	0.0000	0.9375	0.9281	—	0.8969	0.8932	0.8631	3B	0.8700	0.8784	0.8969	0.9017	0.9375
15/16-20 UNEF	2A	0.0014	0.9361	0.9280	—	0.9036	0.8991	0.8766	2B	0.883	0.895	0.9050	0.9109	0.9375
	3A	0.0000	0.9375	0.9294	—	0.9050	0.9016	0.8780	3B	0.8830	0.8911	0.9050	0.9094	0.9375
15/16-28 UN	2A	0.0012	0.9363	0.9298	—	0.9131	0.9092	0.8938	2B	0.899	0.907	0.9143	0.9194	0.9375
	3A	0.0000	0.9375	0.9310	—	0.9143	0.9113	0.8950	3B	0.8990	0.9051	0.9143	0.9181	0.9375
15/16-32 UN	2A	0.0011	0.9364	0.9304	—	0.9161	0.9123	0.8992	2B	0.904	0.911	0.9172	0.9221	0.9375
	3A	0.0000	0.9375	0.9315	—	0.9172	0.9144	0.9003	3B	0.9040	0.9094	0.9172	0.9209	0.9375
1-8 UNC	1A	0.0020	0.9980	0.9755	—	0.9168	0.9067	0.8492	1B	0.865	0.890	0.9188	0.9320	1.0000
	2A	0.0020	0.9980	0.9830	0.9755	0.9168	0.9101	0.8492	2B	0.865	0.890	0.9188	0.9276	1.0000
	3A	0.0000	1.0000	0.9850	—	0.9188	0.9137	0.8512	3B	0.8650	0.8797	0.9188	0.9254	1.0000
1-10 UNS	2A	0.0018	0.9982	0.9853	—	0.9332	0.9270	0.8791	2B	0.892	0.913	0.9350	0.9430	1.0000
1-12 UNF	1A	0.0018	0.9982	0.9810	—	0.9441	0.9353	0.8990	1B	0.910	0.928	0.9459	0.9573	1.0000
	2A	0.0018	0.9982	0.9868	—	0.9441	0.9382	0.8990	2B	0.910	0.928	0.9459	0.9535	1.0000
	3A	0.0000	1.0000	0.9886	—	0.9459	0.9415	0.9008	3B	0.9100	0.9198	0.9459	0.9516	1.0000
1-14 UNS[f]	1A	0.0017	0.9983	0.9828	—	0.9519	0.9435	0.9132	1B	0.923	0.938	0.9536	0.9645	1.0000
	2A	0.0016	0.9894	0.9881	—	0.9520	0.9467	0.9133	2B	0.923	0.938	0.9536	0.9605	1.0000
	3A	0.0000	1.0000	0.9897	—	0.9536	0.9496	0.9149	3B	0.9230	0.9315	0.9536	0.9588	1.0000
1-16 UN	2A	0.0015	0.9985	0.9891	—	0.9579	0.9529	0.9241	2B	0.932	0.946	0.9594	0.9659	1.0000
	3A	0.0000	1.0000	0.9906	—	0.9594	0.9557	0.9256	3B	0.9320	0.9409	0.9594	0.9643	1.0000
1-18 UNS	2A	0.0014	0.9986	0.9899	—	0.9625	0.9578	0.9324	2B	0.940	0.953	0.9639	0.9701	1.0000

1A to be changed to 1A[g]

.9894 should be .9984

In future edition, a corresponding footnote will be added to the end of this table:
[g] While still included in this table, 14UNS-1A is no longer referenced as a nominal size and class in the standard.

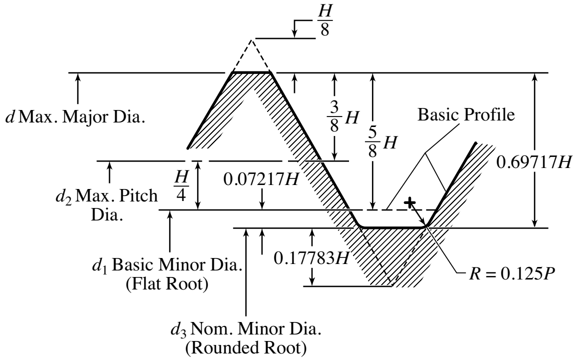


Fig. 3. External Thread Design M Profile with No Allowance (Fundamental Deviation) (Flanks at Maximum Material Condition). For Dimensions see Table 3

Fig. 4 to be adjusted in next MH edition per current standard for correct proportion. See next page for example of correct version.

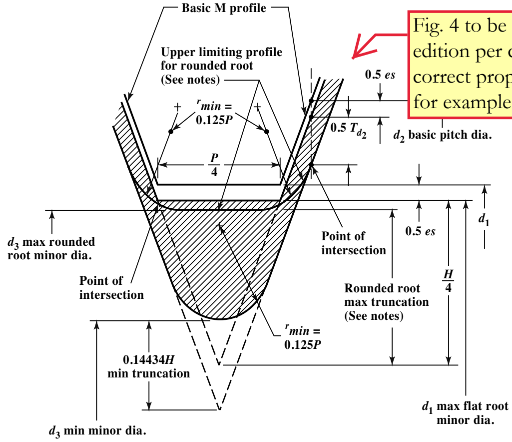


Fig. 4. M Profile, External Thread Root, Upper and Lower Limiting Profiles for $r_{min} = 0.125\,P$ and for Flat Root (Shown for Tolerance Position g)

Notes:

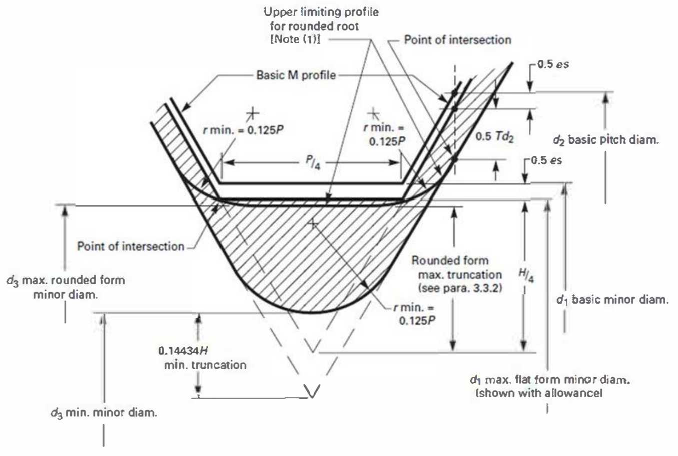
1) "Section lined" portions identify tolerance zone and unshaded portions identify allowance (fundamental deviation).
2) The upper limiting profile for rounded root is not a design profile; rather it indicates the limiting acceptable condition for the rounded root which will pass a GO thread gage.
3) Max truncation $= \frac{H}{4} - r_{min}\left(1 - \cos\left[60° - \arccos\left(1 - \frac{T_{d2}}{4r_{min}}\right)\right]\right)$

where H = Height of fundamental triangle

r_{min} = Minimum external thread root radius

T_{d2} = Tolerance on pitch diameter of external threasd

The below showing the revised proportion of p. 2018, Fig. 4, for future adjustment of this figure, per the ASME standard, is shown below.



GENERAL NOTE: Section-lined portions identify tolerance zone and unshaded portions identify allowance (fundamental deviation).

NOTE:

(1) The upper limiting profile for rounded root form allows no tolerance for flank wear of a tool producing it and is therefore not to be used as a design profile. Rather, it is an indication of the limiting acceptable condition for the rounded root form which will pass a GO thread gage.

Fig. 5 M Profile, External Thread Root, Upper and Lower Limiting Profiles for r min. $= 0.125P$ and for Flat Root Form (Shown for Tolerance Position g)

Internal Threads:

Min major dia. = basic major dia. + *EI* (Table 6)

Min pitch dia. = basic major dia. − 0.6495191*P* (Table 3) + *EI* for D_2 (Table 6)

Max pitch dia. = min pitch dia. + TD_2 (Table 10)

Max major dia. = max pitch dia. + 0.7938566*P* (Table 3)

Min minor dia. = min major dia. − 1.0825318*P* (Table 3)

Max minor dia. = min minor dia. + TD_1 (Table 8)

External Threads:

Max major dia. = basic major dia. − *es* (Table 6) (Note that *es* is an absolute value.)

Min major dia. = max major dia. − *Td* (Table 9)

Max pitch dia. = basic major dia. − 0.6495191*P* (Table 3) − *es* for d_2 (Table 6)

Min pitch dia. = max pitch dia. − Td_2 (Table 11)

Max flat form minor dia. = max pitch dia. − 0.433013*P* (Table 3)

Max rounded root minor dia. = max pitch dia. − 2 × max trunc. (See Fig. 4)

Min rounded root minor dia. = min pitch dia. − 0.616025*P* (Table 3)

Min root radius = 0.125*P*

Equation identified as incorrect in older ANSI standard; not in new standard. Correct to read:

Max rounded root minor dia.=max pitch dia. - H + 2 x max trunc. (see Fig. 4)

Table 8. ANSI Standard Minor Di[illegible]
Metric Threads TD_1 *ISO 965/1* *A*[illegible]

Pitch *P*	T[illegible]				
	4	5	[illegible]	[illegible]	[illegible]
0.2	0.038	…	[illegible]	[illegible]	[illegible]
0.25	0.045	0.056	[illegible]	[illegible]	[illegible]
0.3	0.053	0.067	0.085	…	…
0.35	0.063	0.080	0.100	…	…
0.4	0.071	0.090	0.112	…	…
0.45	0.080	0.100	0.125	…	…
0.5	0.090	0.112	0.140	0.180	…
0.6	0.100	0.125	0.160	0.200	…
0.7	0.112	0.140	0.180	0.224	…
0.75	0.118	0.150	0.190	0.236	…
0.8	0.125	0.160	0.200	0.250	0.315
1	0.150	0.190	0.236	0.300	0.375
1.25	0.170	0.212	0.265	0.335	0.425
1.5	0.190	0.236	0.300	0.375	0.475
1.75	0.212	0.265	0.335	0.425	0.530
2	0.236	0.300	0.375	0.475	0.600
2.5	0.280	0.355	0.450	0.560	0.710
3	0.315	0.400	0.500	0.630	0.800
3.5	0.355	0.450	0.560	0.710	0.900
4	0.375	0.475	0.600	0.750	0.950
4.5	0.425	0.530	0.670	0.850	1.060
5	0.450	0.560	0.710	0.900	1.120
5.5	0.475	0.600	0.750	0.950	1.180
6	0.500	0.630	0.800	1.000	1.250
8	0.630	0.800	1.000	1.250	1.600

[a] Tabulated in this standard for M internal threads.
All dimensions are in millimeters.

3P

Corrected 1.0700 (previously was incorrectly 0.0700)

Table 8b. Limiting Dimensions of American National Standard Centralizing Acme Single-Start Screw Threads, Classes 2C, 3C, and 4C *ANSI/ASME B1.5-1997 (R2014)*

Nominal Diameter, *D*		½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½
Threads per Inch[a]		10	8	6	6	5	5	5	4	4
Limiting Diameters		**External Threads**								
Classes 2C, 3C, and 4C, Major Diameter	Max	0.5000	0.6250	0.7500	0.8750	1.0000	1.1250	1.2500	1.3750	1.5000
Class 2C, Major Diameter	Min	0.4975	0.6222	0.7470	0.8717	0.9965	1.1213	1.2461	1.3709	1.4957
Class 3C, Major Diameter	Min	0.4989	0.6238	0.7487	0.8736	0.9985	1.1234	1.2483	1.3732	1.4982
Class 4C, Major Diameter	Min	0.4993	0.6242	0.7491	0.8741	0.9990	1.1239	1.2489	1.3738	1.4988
Classes 2C, 3C, and 4C, Minor Diameter	Max	0.3800	0.4800	0.5633	0.6883	0.7800	0.9050	1.0300	1.1050	1.2300
Class 2C, Minor Diameter	Min	0.3594	0.4570	0.5371	0.6615	0.7509	0.8753	0.9998	1.0719	1.1965
Class 3C, Minor Diameter	Min	0.3704	0.4693	0.5511	0.6758	0.7664	0.8912	1.0159	1.0896	1.2144
Class 4C, Minor Diameter	Min	0.3731	0.4723	0.5546	0.6794	0.7703	0.8951	1.0199	1.0940	1.2188
Class 2C, Pitch Diameter	Max	0.4443	0.5562	0.6598	0.7842	0.8920	1.0165	1.1411	1.2406	1.3652
	Min	0.4306	0.5408	0.6424	0.7663	0.8726	0.9967	1.1210	1.2186	1.3429
Class 3C, Pitch Diameter	Max	0.4458	0.5578	0.6615	0.7861	0.8940	1.0186	1.1433	1.2430	1.3677
	Min	0.4394	0.5506	0.6534	0.7778	0.8849	1.0094	1.1339	1.2327	1.3573
Class 4C, Pitch Diameter	Max	0.4472	0.5593	0.6632	0.7880	0.8960	1.0208	1.1455	1.2453	1.3701
	Min	0.4426	0.5542	0.6574	0.7820	0.8895	1.0142	1.1388	1.2380	1.3627
		Internal Threads								
Classes 2C, 3C, and 4C, Major Diameter	Min	0.5007	0.6258	0.7509	0.8759	1.0010	1.1261	1.2511	1.3762	1.5012
Classes 2C and 3C, Major Diameter	Max	0.5032	0.6286	0.7539	0.8792	1.0045	1.1298	1.2550	1.3803	1.5055
Class 4C, Major Diameter	Max	0.5021	0.6274	0.7526	0.8778	1.0030	0.1282	1.2533	1.3785	1.5036
Classes 2C, 3C, and 4C, Minor Diameter	Min	0.4100	0.5125	0.6000	0.7250	0.8200	0.9450	1.0700	1.1500	1.2750
	Max	0.04150	0.5187	0.6083	0.7333	0.8300	0.9550	1.0800	1.1625	1.2875
Class 2C, Pitch Diameter	Min	0.4500	0.5625	0.6667	0.7917	0.9000	1.0250	1.1500	1.2500	1.3750
	Max	0.4637	0.5779	0.6841	0.8096	0.9194	1.0448	1.1701	1.2720	1.3973
Class 3C, Pitch Diameter	Min	0.4500	0.5625	0.6667	0.7917	0.9000	1.0250	1.1500	1.2500	1.3750
	Max	0.4564	0.5697	0.6748	0.8000	0.9091	1.0342	1.1594	1.2603	1.3854
Class 4C, Pitch Diameter	Min	0.4500	0.5625	0.6667	0.7917	0.9000	1.0250	1.1500	1.2500	1.3750
	Max	0.4546	0.5676	0.6725	0.7977	0.9065	1.0316	1.1567	1.2573	1.3824

Footnote c marker added. (Footnote on next page.)

Table 2. Keyway Dimensions and Tolerances for Metric Square and Rectangular Parallel Keys *ANSI/ASME B18.25.1M-1996 (Withdrawn)*

Key size $b \times h$ (mm)	Keyway																
	Width.											Depth				Radius, r	
		Tolerance[a] and Resulting Fits[b]										Shaft, t_1		Hub, t_2			
		Normal Fit				Close Fit		Free Fit									
		Shaft		Hub		Shaft and Hub		Shaft		Hub							
	Basic Size[c]	N9	Fit	JS9	Fit	P9	Fit	H9	Fit	D10	Fit	Basic Size	Toler-ance	Basic Size	Toler-ance	Min.	Max.
2×2	2	−0.004 −0.029	0.010L 0.029T	+0.0125 −0.0125	0.0265L 0.0125T	−0.006 −0.031	0.008L 0.031T	+0.025 0	0.039L 0T	+0.060 +0.020	0.074L 0.020L	1.2	+0.1 0	1	+0.1 0	0.08	0.16
3×3	3											1.8		1.4			
4×4	4	0 −0.030	0.018L 0.030T	+0.0150 −0.0150	0.033L 0.015T	−0.012 −0.042	0.006L 0.042T	+0.030 0	0.048L 0T	+0.078 +0.030	0.096L 0.030L	2.5		1.8			
5×3	5											1.8		1.4		0.16	0.25
5×5	6											3		2.8			
6×4	6											2.5		1.8			
6×6	6											3.5		2.8			
8×5	8											3		2.8			
8×7	8	0 −0.036	0.022L 0.036T	+0.0180 −0.0180	0.040L 0.018T	−0.015 −0.051	0.007L 0.051T	+0.036 0	0.058L 0T	+0.098 +0.040	0.120L 0.040L	4	+0.2 0	3.3	+0.1 0		
10×6	10											3.5	+0.1 0	2.8	+0.1 0	0.25	0.4
10×8	10											5	+0.2 0	3.3	+0.2 0		
12×6	12	0 −0.043	0.027L 0.043T	+0.0215 −0.0215	0.0485L 0.0215T	−0.018 −0.061	0.009L 0.061T	+0.043 0	0.070L 0T	+0.120 +0.050	0.147L 0.050L	3.5	+0.1 0	2.8	+0.1 0		
12×8	12											5	+0.2 0	3.3	+0.2		
14×6	14											3.5	+0.1 0	2.8	+0.1 0		
14×9	14											5.5	+0.2 0	3.8	+0.2 0		
16×7	16											4		3.3			
16×10	16											6		4.3			
18×7	18											4		3.3			
18×11	18											7		4.4			

0.6 corrected (was 0.06); also footnote c marker added

Footnote c marker added.

Table 2. *(Continued)* **Keyway Dimensions and Tolerances for Metric Square and Rectangular Parallel Keys** *ANSI/ASME B18.25.1M-1996 (Withdrawn)*

Key size $b \times h$ (mm)	Keyway: Width. Basic Size[c]	Normal Fit, Shaft: N9	Normal Fit, Shaft: Fit	Normal Fit, Hub: JS9	Normal Fit, Hub: Fit	Close Fit, Shaft and Hub: P9	Close Fit, Shaft and Hub: Fit	Free Fit, Shaft: H9	Free Fit, Shaft: Fit	Free Fit, Hub: D10	Free Fit, Hub: Fit	Depth, Shaft t_1: Basic Size	Depth, Shaft t_1: Tolerance	Depth, Hub t_2: Basic Size	Depth, Hub t_2: Tolerance	Radius r: Min.	Radius r: Max.
		Tolerance[a] and Resulting Fits[b]															
20 × 8	20	0 −0.052	0.033L 0.052T	+0.026 −0.026	0.059L 0.026T	−0.022 −0.074	0.011L 0.074T	+0.052 0	0.085L 0T	+0.149 +0.065	0.182L 0.065L	5	+0.2 0	3.3	+0.2 0	0.4	0.6[c]
20 × 12	20											7.5		4.9			
22 × 9	22											5.5		3.8			
22 × 14	22											9		5.4			
25 × 9	25											5.5		3.8			
25 × 14	25											9		5.4			
28 × 10	28											6		4.3			
28 × 16	28											10		6.4			
32 × 11	32	0 −0.062	0.039L 0.062T	+0.031 −0.031	0.070L 0.031T	−0.026 −0.088	0.013L 0.088T	+0.062 0	0.101L 0T	+0.180 +0.080	0.219L 0.080L	7[c]		4.4			
32 × 18	32											11[c]		7.4			
36 × 12	36											7.5[c]		4.9		0.7	1.0
36 × 20	36											12	+0.3 0	8.4	+0.3 0		
40 × 22	40											13		9.4			
45 × 25	45											15		10.4			
50 × 28	50											17		11.4			
56 × 32	56	0 −0.074	0.046L 0.074T	+0.037 −0.037	0.083L 0.037T	−0.032 −0.106	0.014L 0.106T	+0.074 0	0.120L 0T	+0.220 +0.100	0.266L 0.100L	20		12.4		1.2	1.6
63 × 32	63											20		12.4			
70 × 36	70											22		14.4			
80 × 40	80											25		15.4			
90 × 45	90	0 −0.087	0.054L 0.87T	+0.0435 −0.0435	0.0975L 0.0435T	−0.037 −0.1254	0.017L 0.1254T	+0.087 0	0.139L 0T	+0 260 +0.120	0.314L 0.120L	28		17.4		2.0	2.5
100 × 50	100											31		19.5			

[a] Some of the tolerances are expressed as plus-plus. See *Tolerances* on page 2539 for more information.

[b] Resulting fits: L indicates a clearance between the key and keyway; T indicates an interference between the key and keyway.

[c] Values changed for accuracy from that given in ANSI/ASME 18.25.1M-1996 (Withdrawn).

Footnote c revised.

Table 5. Units Outside SI, Accepted for Use with SI

Name	Symbol	Value in SI Units
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 1440 min = 86400 s
liter	L	1 L = 1 dm^3 = 10^{-3} m
metric ton	t	1 t = 10^3 kg =2205 lb
bel	B	1 B = 10 dB
degree (angle)	°	1° = π/180 rad
minute (angle)	′	1′ = (1/60)° = (π/10800) rad
second (angle)	″	1″ = (1/60)′ = (π/6480000) rad
electron volt	eV	1 eV = 1.60218 × 10^{-19} J
unified atomic mass unit	Da or u	1 u = 1.66054 × 10^{-27} kg
astronomical unit	au	1 au = 1.49598 × 10^{11} m
nautical mile	nmi	1 nmi = 1852 m
knot	kn	1 kn = 1 nmi·h^{-1} = 0.514444 m·s^{-1}
are	a	1 a = 100 m^2
hectare	ha	1 ha = 100 a = 10^4 m^2
bar	bar	1 bar = 10^2 kPa = 10^5 Pa
ångström	Å	1 Å = 0.1 nm = 10^{-10} m
curie	Ci	1 Ci = 3.7 × 10^{10} Bq
roentgen	R	1 R = 2.58 × 10^{-4} C·kg^{-1}
rad	rad	1 rad = 10^{-2} Gy
rem	rem	1 rem = 10^2 Sv

Dot/decimal placement corrected in 2.58 in roentgen equation.

Table 6. SI Prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^1	deca	da	10^{-1}	deci	d
10^2	hecto	h	10^{-2}	centi	c
10^3	kilo	k	10^{-3}	milli	m
10^6	mega	M	10^{-6}	micro	µ
10^9	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a

Standard of Length and the US Customary Unit System

Among all units of measure, the history of standard of length traces a clear path from the less scientific approach of physical object standards used in past centuries to the today's precise standards, based on physical constants on an atomic level.

The primary Imperial yard was set by the British Weights and Measures Act of 1824. But it was partially destroyed in a fire in 1834, and replaced by a new standard, made of an alloy of copper, tin, and zinc. Between 1845 and 1855, forty copies of the Imperial yard were cast. Bronze yard No. 11 went to the United States, an exact copy of the British Imperial yard, in both form and material.

By an Act of Congress, in 1866, the US legally recognized the meter as a standard of length equal to 39/39.37 = 0.9144 yard; for commercial purposes, 1 meter = 39.37 inches.