Introduction to Aluminum Alloys and Tempers
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CHAPTER 4

Understanding the Aluminum Temper Designation System

This chapter provides additional detail and illustrations for the use of temper designations in the aluminum industry today for both wrought and cast alloys. This discussion expands on the basic Aluminum Association Temper Designation System as described in Chapter 2. All standard tempers (i.e., those recognized by the industry because they have been registered by the Aluminum Association Technical Committee on Product Standards) are published either in *Aluminum Standards and Data* or in the *Alloy and Temper Registration Records* together with the procedures for registering alloys.

Tempers for Wrought Aluminum Alloys

As noted earlier, temper designations are alphanumeric designations appended to the alloy designations that convey to the producer and user alike information about the general manner in which the alloy has been mechanically and/or thermally treated to achieve the properties desired. Most tempers have specific mechanical properties associated with them, and satisfactory achievement of the intended temper is generally indicated by whether the specified properties have been achieved. The temper designation does *not* indicate precise details of how the material has been treated, such as specific amounts of reduction during cold rolling, or the temperatures used in the thermal treatments.

Topics covered in this chapter include:

- Review of basic temper designations and their major variations
- Applications and variations of the O temper

- Applications and variations of the F temper
- Applications and variations of the W temper
- Applications and variations of the H tempers
- Applications and variations of the T tempers

a. Identifying cold work
b. Identifying stabilization treatments
c. Identifying partial annealing treatments
d. Identifying specific products (e.g., embossed sheet)
e. Applications and variations of the T tempers
f. Identifying stress relief (TX51, TX510, TX511; TX52)
g. Identifying modifications in quenching (T5 versus T6; T6 versus T61)
h. Heat treatment by nonproducer (heat treater or fabricator) (TX2)
i. Applications of H or T Tempers for Specific Performance (corrosion resistance; identifying tempers for special or premium properties; T736 and T74)

As background and useful reference material in understanding more about aluminum alloy temper designations, the typical mechanical properties of representative wrought and cast aluminum alloys are presented in Tables 1 and 2, respectively.

Table 1 Typical mechanical properties of wrought aluminum alloys(a)

Alloy and temper	Tension: Strength, ksi		Tension: Elongation, %		Hardness, Brinell No., 500 kg load, 10 mm ball	Shear, ultimate shearing strength, ksi	Fatigue, endurance limit(b), ksi	Modulus, modulus of elasticity(c), ksi $\times 10^3$
	Ultimate	Yield	In 2 in. 1/16 in. thick specimen	In 4D 1/2 in. diam specimen				
1060-O	10	4	43	…	19	7	3	10.0
1060-H12	12	11	16	…	23	8	4	10.0
1060-H14	14	13	12	…	26	9	5	10.0
1060-H16	16	15	8	…	30	10	6.5	10.0
1060-H18	19	18	6	…	35	11	6.5	10.0
1100-O	13	5	35	45	23	9	5	10.0
1100-H12	16	15	12	25	28	10	6	10.0
1100-H14	18	17	9	20	32	11	7	10.0
1100-H16	21	20	6	17	38	12	9	10.0
1100-H18	24	22	5	15	44	13	9	10.0
1350-O	12	4	…	(d)	…	8	…	10.0
1350-H12	14	12	…	…	…	9	…	10.0
1350-H14	16	14	…	…	…	10	…	10.0
1350-H16	18	16	…	…	…	11	…	10.0
1350-H19	27	24	…	(e)	…	15	7	10.0
2011-T3	55	43	…	15	95	32	18	10.2
2011-T8	59	45	…	12	100	35	18	10.2

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is about 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 10 in. (e) 1350-H19 wire will have an elongation of approximately 1½% in 10 in. (f) Tempers T361 and T861 were formerly designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on ¼ in. thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1 (continued)

Alloy and temper	Tension: Strength, ksi: Ultimate	Tension: Strength, ksi: Yield	Tension: Elongation, %: In 2 in. 1/16 in. thick specimen	Tension: Elongation, %: In 4D 1/2 in. diam specimen	Hardness, Brinell No., 500 kg load, 10 mm ball	Shear, ultimate shearing strength, ksi	Fatigue, endurance limit(b), ksi	Modulus, modulus of elasticity(c), ksi × 10^3
2014-O	27	14	…	18	45	18	13	10.6
2014-T4, T451	62	42	…	20	105	38	20	10.6
2014-T6, T651	70	60	…	13	135	42	18	10.6
Alclad 2014-O	25	10	21	…	…	18	…	10.5
Alclad 2014-T3	63	40	20	…	…	37	…	10.5
Alclad 2014-T4, T451	61	37	22	…	…	37	…	10.5
Alclad 2014-T6, T651	68	60	10	…	…	41	…	10.5
2017-O	26	10	…	22	45	18	13	10.5
2017-T4, T451	62	40	…	22	105	38	18	10.5
2018-T61	61	46	…	12	120	39	17	10.8
2024-O	27	11	20	22	47	18	13	10.6
2024-T3	70	50	18	…	120	41	20	10.6
2024-T4, T351	68	47	20	19	120	41	20	10.6
2024-T361(f)	72	57	13	…	130	42	18	10.6
Alclad 2024-O	26	11	20	…	…	18	…	10.6
Alclad 2024-T3	65	45	18	…	…	40	…	10.6
Alclad 2024-T4, T351	64	42	19	…	…	40	…	10.6
Alclad 2024-T361(f)	67	63	11	…	…	41	…	10.6
Alclad 2024-T81, T851	65	60	6	…	…	40	…	10.6
Alclad 2024-T861(f)	70	66	6	…	…	42	…	10.6
2025-T6	58	37	…	19	110	35	18	10.4
2036-T4	49	28	24	…	…	…	18(g)	10.3
2117-T4	43	24	…	27	70	28	14	10.3
2124-T851	70	64	…	8	…	…	…	10.6
2218-T72	48	37	…	11	95	30	…	10.8
2219-O	25	11	18	…	…	…	…	10.6
2219-T42	52	27	20	…	…	…	…	10.6
2219-T31, T351	52	36	17	…	…	…	…	10.6
2219-T37	57	46	11	…	…	…	…	10.6
2219-T62	60	42	10	…	…	…	15	10.6
2219-T81, T851	66	51	10	…	…	…	15	10.6
2219-T87	69	57	10	…	…	…	15	10.6
2618-T61	64	54	…	10	115	38	18	10.8
3003-O	16	6	30	40	28	11	7	10.0
3003-H12	19	18	10	20	35	12	8	10.0
3003-H14	22	21	8	16	40	14	9	10.0
3003-H16	26	25	5	14	47	15	10	10.0
3003-H18	29	27	4	10	55	16	10	10.0
Alclad 3003-O	16	6	30	40	…	11	…	10.0
Alclad 3003-H12	19	18	10	20	…	12	…	10.0
Alclad 3003-H14	22	21	8	16	…	14	…	10.0
Alclad 3003-H16	26	25	5	14	…	15	…	10.0
Alclad 3003-H18	29	27	4	10	…	16	…	10.0

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is about 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 10 in. (e) 1350-H19 wire will have an elongation of approximately 1½% in 10 in. (f) Tempers T361 and T861 were formerly designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on ¼ in. thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1 (continued)

	Tension							
	Strength, ksi		Elongation, %					
Alloy and temper	Ultimate	Yield	In 2 in. 1/16 in. thick specimen	In 4D 1/2 in. diam specimen	Hardness, Brinell No., 500 kg load, 10 mm ball	Shear, ultimate shearing strength, ksi	Fatigue, endurance limit(b), ksi	Modulus, modulus of elasticity(c), ksi $\times 10^3$
3004-O	26	10	20	25	45	16	14	10.0
3004-H32	31	25	10	17	52	17	15	10.0
3004-H34	35	29	9	12	63	18	15	10.0
3004-H36	38	33	5	9	70	20	16	10.0
3004-H38	41	36	5	6	77	21	16	10
Alclad 3004-O	26	10	20	25	…	16	…	10.0
Alclad 3004-H32	31	25	10	17	…	17	…	10.0
Alclad 3004-H34	35	29	9	12	…	18	…	10.0
Alclad 3004-H36	38	33	5	9	…	20	…	10.0
Alclad 3004-H38	41	36	5	6	…	21	…	10.0
3105-O	17	8	24	…	…	12	…	10.0
3105-H12	22	19	7	…	…	14	…	10.0
3105-H14	25	22	5	…	…	15	…	10.0
3105-H16	28	25	4	…	…	16	…	10.0
3105-H18	31	28	3	…	…	17	…	10.0
3105-H25	26	23	8	…	…	15	…	10.0
4032-T6	55	46	…	9	120	38	16	11.4
5005-O	18	6	25	…	28	11	…	10.0
5005-H12	20	19	10	…	…	14	…	10.0
5005-H14	23	22	6	…	…	14	…	10.0
5005-H16	26	25	5	…	…	15	…	10.0
5005-H18	29	28	4	…	…	16	…	10.0
5005-H32	20	17	11	…	36	14	…	10.0
5005-H34	23	20	8	…	41	14	…	10.0
5005-H36	26	24	6	…	46	15	…	10.0
5005-H38	29	27	5	…	51	16	…	10.0
5050-O	21	8	24	…	36	15	12	10.0
5050-H32	25	21	9	…	46	17	13	10.0
5050-H34	28	24	8	…	53	18	13	10.0
5050-H36	30	26	7	…	58	19	14	10.0
5050-H38	32	29	6	…	63	20	14	10.0
5052-O	28	13	25	30	47	18	16	10.2
5052-H32	33	28	12	18	60	20	17	10.2
5052-H34	38	31	10	14	68	21	18	10.2
5052-H36	40	35	8	10	73	23	19	10.2
5052-H38	42	37	7	8	77	24	20	10.2
5056-O	42	22	…	35	65	26	20	10.3
5056-H18	63	59	…	10	105	34	22	10.3
5056-H38	60	50	…	15	100	32	22	10.3
5083-O	42	21	…	22	…	25	…	10.3
5083-H321, H116	46	33	…	16	…	…	23	10.3

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is about 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 10 in. (e) 1350-H19 wire will have an elongation of approximately 1½% in 10 in. (f) Tempers T361 and T861 were formerly designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on ¼ in. thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1 (continued)

	Tension							
	Strength, ksi		Elongation, %					
Alloy and temper	Ultimate	Yield	In 2 in. 1/16 in. thick specimen	In 4D 1/2 in. diam specimen	Hardness, Brinell No., 500 kg load, 10 mm ball	Shear, ultimate shearing strength, ksi	Fatigue, endurance limit(b), ksi	Modulus, modulus of elasticity(c), ksi $\times 10^3$
5086-O	38	17	22	…	…	23	…	10.3
5086-H32, H116	42	30	12	…	…	…	…	10.3.
5086-H34	47	37	10	…	…	27	…	10.3
5086-H112	39	19	14	…	…	…	…	10.3
5154-O	35	17	27	…	58	22	17	10.2
5154-H32	39	30	15	…	67	22	18	10.2
5154-H34	42	33	13	…	73	24	19	10.2
5154-H36	45	36	12	…	78	26	20	10.2
5154-H38	48	39	10	…	80	28	21	10.2
5154-H112	35	17	25	…	63	…	17	10.2
5252-H25	34	25	11	…	68	21	…	10.0
5252-H38, H28	41	35	5	…	75	23	…	10.0
5254-O	35	17	27	…	58	22	17	10.2
5254-H32	39	30	15	…	67	22	18	10.2
5254-H34	42	33	13	…	73	24	19	10.2
5254-H36	45	36	12	…	78	26	20	10.2
5254-H38	48	39	10	…	80	28	21	10.2
5254-H112	35	17	25	…	63	…	17	10.2
5454-O	36	17	22	…	62	23	…	10.2
5454-H32	40	30	10	…	73	24	…	10.2
5454-H34	44	35	10	…	81	26	…	10.2
5454-H111	38	26	14	…	70	23	…	10.2
5454-H112	36	18	18	…	62	23	…	10.2
5456-O	45	23	…	24	…	…	…	10.3
5456-H25	45	24	…	22	…	…	…	10.3
5456-H321, H116	51	37	…	16	90	30	…	10.3
5457-O	19	7	22	…	32	12	…	10.0
5457-H25	26	23	12	…	48	16	…	10.0
5457-H38, H28	30	27	6	…	55	18	…	10.0
5652-O	28	13	25	30	47	18	16	10.2
5652-H32	33	28	12	18	60	20	17	10.2
5652-H34	38	31	10	14	68	21	18	10.2
5652-H36	40	35	8	10	73	23	19	10.2
5652-H38	42	37	7	8	77	24	20	10.2
5657-H25	23	20	12	…	40	12	…	10.0
5657-H38, H28	28	24	7	…	50	15	…	10.0
6061-O	18	8	25	30	30	12	9	10.0
6061-T4, T451	35	21	22	25	65	24	14	10.0
6061-T6, T651	45	40	12	17	95	30	14	10.0
Alclad 6061-O	17	7	25	…	…	11	…	10.0
Alclad 6061-T4, T451	33	19	22	…	…	22	…	10.0

(continued)

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Table 1 (continued)

Alloy and temper	Tension: Strength, ksi: Ultimate	Tension: Strength, ksi: Yield	Tension: Elongation, %: In 2 in. 1/16 in. thick specimen	Tension: Elongation, %: In 4D 1/2 in. diam specimen	Hardness, Brinell No., 500 kg load, 10 mm ball	Shear, ultimate shearing strength, ksi	Fatigue, endurance limit(b), ksi	Modulus, modulus of elasticity(c), ksi $\times 10^3$
Alclad 6061-T6, T651	42	37	12	…	…	27	…	10.0
6063-O	13	7	…	…	25	10	8	10.0
6063-T1	22	13	20	…	42	14	9	10.0
6063-T4	25	13	22	…	…	…	…	10.0
6063-T5	27	21	12	…	60	17	10	10.0
6063-T6	35	31	12	…	73	22	10	10.0
6063-T83	37	35	9	…	82	22	…	10.0
6063-T831	30	27	10	…	70	18	…	10.0
6063-T832	42	39	12	…	95	27	…	10.0
6066-O	22	12	…	18	43	14	…	10.0
6066-T4, T451	52	30	…	18	90	29	…	10.0
6066-T6, T651	57	52	…	12	120	34	16	10.0
6070-T6	55	51	10	…	…	34	14	10.0
6101-H111	14	11	…	…	…	…	…	10.0
6101-T6	32	28	15(h)	…	71	20	…	10.0
6262-T9	58	55	…	10	120	35	13	10.0
6351-T4	36	22	20	…	…	…	…	10.0
6351-T6	45	41	14	…	95	29	13	10.0
6463-T1	22	13	20	…	42	14	10	10.0
6463-T5	27	21	12	…	60	17	10	10.0
6463-T6	35	31	12	…	74	22	10	10.0
7049-T73	75	65	…	12	135	44	…	10.4
7049-T7352	75	63	…	11	135	43	…	10.4
7050-T73510, T73511	72	63	…	12	…	…	…	10.4
7050-T7451(i)	76	68	…	11	…	44	…	10.4
7050-T7651	80	71	…	11	…	47	…	10.4
7075-O	33	15	17	16	60	22	…	10.4
7075-T6, T651	83	73	11	11	150	48	23	10.4
Alclad 7075-O	32	14	17	…	…	22	…	10.4
Alclad 7075-T6, T651	76	67	11	…	…	46	…	10.4
7175-T74	76	66	…	11	135	42	23	10.4
7178-O	33	15	15	16	…	…	…	10.4
7178-T6, T651	88	78	10	11	…	…	…	10.4
7178-T76, T7651	83	73	…	11	…	…	…	10.3
Alclad 7178-O	32	14	16	…	…	…	…	10.4
Alclad 7178-T6, T651	81	71	10	…	…	…	…	10.4
7475-T61	82	71	11	…	…	…	…	10.2
7475-T651	85	74	…	13	…	…	…	10.4
7475-T7351	72	61	…	13	…	…	…	10.4
7475-T761	75	65	12	…	…	…	…	10.2
7475-T7651	77	67	…	12	…	…	…	10.4
Alclad 7475-T61	75	66	11	…	…	…	…	10.2
Alclad 7475-T761	71	61	12	…	…	…	…	10.2
8176-H24	17	14	15	…	…	10	…	10.0

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Table 1M Typical mechanical properties of wrought aluminum alloys, (metric)(a)

Alloy and temper	Tension				Hardness, Brinell No., 500 kgf load, 10 mm ball	Shear, ultimate shearing strength, MPa	Fatigue, endurance limit(b), MPa	Modulus, modulus of elasticity(c), MPa × 10^3
	Strength, MPa		Elongation, %					
	Ultimate	Yield	In 50 mm 1.60 mm thick specimen	In 5D 12.5 mm diam specimen				
1060-O	70	30	43	…	19	50	20	69
1060-H12	85	75	16	…	23	55	30	69
1060-H14	100	90	12	…	26	60	35	69
1060-H16	115	105	8	…	30	70	45	69
1060-H18	130	125	6	…	35	75	45	69
1100-O	90	35	35	42	23	60	35	69
1100-H12	110	105	12	22	28	70	40	69
1100-H14	125	115	9	18	32	75	50	69
1100-H16	145	140	6	15	38	85	60	69
1100-H18	165	150	5	13	44	90	60	69
1350-O	85	30	…	(d)	…	55	…	69
1350-H12	95	85	…	…	…	60	…	69
1350-H14	110	95	…	…	…	70	…	69
1350-H16	125	110	…	…	…	75	…	69
1350-H19	185	165	…	(e)	…	105	50	69
2011-T3	380	295	…	13	95	220	125	70
2011-T8	405	310	…	10	100	240	125	70
2014-O	185	95	…	16	45	125	90	73
2014-T4, T451	425	290	…	18	105	260	140	73
2014-T6, T651	485	415	…	11	135	290	125	73
Alclad 2014-O	170	70	21	…	…	125	…	73
Alclad 2014-T3	435	275	20	…	…	255	…	73
Alclad 2014-T4, T451	421	255	22	…	…	255	…	73
Alclad 2014-T6, T651	470	415	10	…	…	285	…	73
2017-O	180	70	…	20	45	125	90	73
2017-T4, T451	425	275	…	20	105	260	125	73
2018-T61	420	315	21	10	120	270	115	74
2024-O	185	75	20	20	47	125	90	73
2024-T3	485	345	18	…	120	285	140	73
2024-T4, T351	472	325	20	17	120	285	140	73
2024-T361(f)	495	395	13	…	130	290	125	73
Alclad 2024-O	180	75	20	…	…	125	…	73
Alclad 2024-T3	450	310	18	…	…	275	…	73
Alclad 2024-T4, T351	440	290	19	…	…	275	…	73
Alclad 2024-T361(f)	460	365	11	…	…	285	…	73
Alclad 2024-T81, T851	450	415	6	…	…	275	…	73
Alclad 2024-T861(f)	485	455	6	…	…	290	…	73
2025-T6	400	255	…	17	110	240	125	72
2036-T4	340	195	24	…	…	205	125(g)	71
2117-T4	295	165	…	24	70	195	95	71
2124-T851	485	440	…	8	…	…	…	73

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is approximately 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 250 mm. (e) 1350-H19 wire will have an elongation of approximately 1½% in 250 mm. (f) Tempers T361 and T861 formerly were designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on 6.3 mm thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1M (continued)

Alloy and temper	Tension: Strength, MPa: Ultimate	Tension: Strength, MPa: Yield	Tension: Elongation, %: In 50 mm 1.60 mm thick specimen	Tension: Elongation, %: In 5D 12.5 mm diam specimen	Hardness, Brinell No., 500 kgf load, 10 mm ball	Shear, ultimate shearing strength, MPa	Fatigue, endurance limit(b), MPa	Modulus, modulus of elasticity(c), MPa $\times 10^3$
2218-T72	330	255	…	9	95	205	…	74
2219-O	170	75	18	…	…	…	…	73
2219-T42	360	185	20	…	…	…	…	73
2219-T31, T351	360	250	17	…	…	…	…	73
2219-T37	395	215	11	…	…	…	…	73
2219-T62	415	290	10	…	…	…	105	73
2219-T81, T851	455	350	10	…	…	…	105	73
2219-T87	475	395	10	…	…	…	105	73
2618-T61	440	370	…	10	115	260	90	73
3003-O	110	40	30	37	28	75	50	69
3003-H12	130	125	10	18	35	85	55	69
3003-H14	150	145	8	14	40	95	60	69
3003-H16	175	170	5	12	47	105	70	69
3003-H18	200	185	4	9	55	110	70	69
Alclad 3003-O	110	40	30	37	…	75	…	69
Alclad 3003-H12	130	125	10	18	…	85	…	69
Alclad 3003-H14	150	145	8	14	…	95	…	69
Alclad 3003-H16	175	170	5	12	…	105	…	69
Alclad 3003-H18	200	185	4	9	…	110	…	69
3004-O	180	70	20	22	45	110	95	69
3004-H32	215	170	10	15	52	115	105	69
3004-H34	240	200	9	10	63	125	105	69
3004-H36	260	230	5	8	70	140	110	69
3004-H38	285	250	5	5	77	145	110	69
Alclad 3004-O	180	70	20	22	…	110	…	69
Alclad 3004-H32	215	170	10	15	…	115	…	69
Alclad 3004-H34	240	200	9	10	…	125	…	69
Alclad 3004-H36	260	230	5	8	…	140	…	69
Alclad 3004-H38	285	250	5	5	…	145	…	69
3105-O	115	55	24	…	…	85	…	69
3105-H12	150	130	7	…	…	95	…	69
3105-H14	170	150	5	…	…	105	…	69
3105-H16	195	170	4	…	…	110	…	69
3105-H18	215	195	3	…	…	115	…	69
3105-H25	180	160	8	…	…	105	…	69
4032-T6	380	315	…	9	120	260	110	79
5005-O	125	40	25	…	28	75	…	69
5005-H12	140	130	10	…	…	95	…	69
5005-H14	160	150	6	…	…	95	…	69
5005-H16	180	170	5	…	…	105	…	69
5005-H18	200	195	4	…	…	110	…	69

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is approximately 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 250 mm. (e) 1350-H19 wire will have an elongation of approximately 1½% in 250 mm. (f) Tempers T361 and T861 formerly were designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on 6.3 mm thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1M (continued)

Alloy and temper	Tension: Strength, MPa: Ultimate	Tension: Strength, MPa: Yield	Tension: Elongation, %: In 50 mm 1.60 mm thick specimen	Tension: Elongation, %: In 5D 12.5 mm diam specimen	Hardness, Brinell No., 500 kgf load, 10 mm ball	Shear, ultimate shearing strength, MPa	Fatigue, endurance limit(b), MPa	Modulus, modulus of elasticity(c), MPa × 10^3
5005-H32	140	115	11	…	36	95	…	69
5005-H34	160	140	8	…	41	95	…	69
5005-H36	180	165	6	…	46	105	…	69
5005-H38	200	185	5	…	51	110	…	69
5050-O	145	55	24	…	36	105	85	69
5050-H32	170	145	9	…	46	115	90	69
5050-H34	190	165	8	…	53	125	90	69
5050-H36	205	180	7	…	58	130	95	69
5050-H38	220	200	6	…	63	140	95	69
5052-O	195	90	25	27	47	125	110	70
5052-H32	230	195	12	16	60	140	115	70
5052-H34	260	215	10	12	68	145	125	70
5052-H36	275	240	8	9	73	160	130	70
5052-H38	290	255	7	7	77	165	140	70
5056-O	290	150	…	32	65	180	140	71
5056-H18	435	405	…	9	105	235	150	71
5056-H38	415	345	…	13	100	220	150	71
5083-O	290	145	…	20	…	170	…	71
5083-H321, H116	315	230	…	14	…	…	160	71
5086-O	260	115	22	…	…	165	…	71
5086-H32, H116	290	205	12	…	…	…	…	71
5086-H34	325	255	10	…	…	185	…	71
5086-H112	270	130	14	…	…	…	…	71
5154-O	240	115	27	…	58	150	115	70
5154-H32	270	205	15	…	67	150	125	70
5154-H34	290	230	13	…	73	165	130	70
5154-H36	310	250	12	…	78	180	140	70
5154-H38	330	270	10	…	80	195	145	70
5154-H112	240	115	25	…	63	…	115	70
5252-H25	235	170	11	…	68	145	…	69
5252-H38, H28	285	240	5	…	75	160	…	69
5254-O	240	115	27	…	58	150	115	70
5254-H32	270	205	15	…	67	150	125	70
5254-H34	290	230	13	…	73	165	130	70
5254-H36	310	250	12	…	78	180	140	70
5254-H38	330	270	10	…	80	195	145	70
5254-H112	240	115	25	…	63	…	115	70
5454-O	250	115	22	…	62	160	…	70
5454-H32	275	205	10	…	73	165	…	70
5454-H34	305	240	10	…	81	180	…	70
5454-H111	260	180	14	…	70	160	…	70

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is approximately 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 250 mm. (e) 1350-H19 wire will have an elongation of approximately 1½% in 250 mm. (f) Tempers T361 and T861 formerly were designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on 6.3 mm thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1M (continued)

Alloy and temper	Tension: Strength, MPa: Ultimate	Tension: Strength, MPa: Yield	Tension: Elongation, %: In 50 mm 1.60 mm thick specimen	Tension: Elongation, %: In 5D 12.5 mm diam specimen	Hardness, Brinell No., 500 kgf load, 10 mm ball	Shear, ultimate shearing strength, MPa	Fatigue, endurance limit(b), MPa	Modulus, modulus of elasticity(c), MPa × 10^3
5454-H112	250	125	18	…	62	160	…	70
5456-O	310	160	…	22	…	…	…	71
5456-H25	310	165	…	20	…	…	…	71
5456-H321, H116	350	255	…	14	90	205	…	71
5457-O	130	50	22	…	32	85	…	69
5457-H25	180	160	12	…	48	110	…	69
5457-H38, H28	205	185	6	…	55	125	…	69
5652-O	195	90	25	27	47	125	110	70
5652-H32	230	195	12	16	60	140	115	70
5652-H34	260	215	10	12	68	145	125	70
5652-H36	275	240	8	9	73	160	130	70
5652-H38	290	255	7	7	77	165	140	70
5657-H25	160	140	12	…	40	95	…	69
5657-H38, H28	195	165	7	…	50	105	…	69
6061-O	125	55	25	27	30	85	60	69
6061-T4, T451	240	145	22	22	65	165	95	69
6061-T6, T651	310	275	12	15	95	205	95	69
Alclad 6061-O	115	50	25	…	…	75	…	69
Alclad 6061-T4, T451	230	130	22	…	…	150	…	69
Alclad 6061-T6, T651	290	255	12	…	…	185	…	69
6063-O	90	50	…	…	25	70	55	69
6063-T1	150	90	20	…	42	95	60	69
6063-T4	170	90	22	…	…	…	…	69
6063-T5	185	145	12	…	60	115	70	69
6063-T6	240	215	12	…	73	150	70	69
6063-T83	255	240	9	…	82	150	…	69
6063-T831	205	185	10	…	70	125	…	69
6063-T832	295	270	12	…	95	185	…	69
6066-O	150	85	…	16	43	95	…	69
6066-T4, T451	360	205	…	16	90	200	…	69
6066-T6, T651	395	360	…	10	120	235	110	69
6070-T6	380	350	10	…	…	235	95	69
6101-H111	95	75	…	…	…	…	…	69
6101-T6	220	195	15(h)	…	71	140	…	69
6262-T9	400	380	…	9	120	240	90	69
6351-T4	250	150	20	…	…	…	…	69
6351-T6	310	285	14	…	95	200	90	69
6463-T1	150	90	20	…	42	95	70	69
6463-T5	185	145	12	…	60	115	70	69
6463-T6	240	215	12	…	74	150	70	69

(continued)

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is approximately 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 250 mm. (e) 1350-H19 wire will have an elongation of approximately 1½% in 250 mm. (f) Tempers T361 and T861 formerly were designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on 6.3 mm thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 1M (continued)

	Tension							
			Elongation, %					
	Strength, MPa		In 50 mm 1.60 mm thick specimen	In 5D 12.5 mm diam specimen	Hardness, Brinell No., 500 kgf load, 10 mm ball	Shear, ultimate shearing strength, MPa	Fatigue, endurance limit(b), MPa	Modulus, modulus of elasticity(c), MPa × 10^3
Alloy and temper	Ultimate	Yield						
7049-T73	515	450	…	10	135	305	…	72
7049-T7352	515	435	…	9	135	295	…	72
7050-T73510, T73511	495	435	…	11	…	…	…	72
7050-T7451(i)	525	470	…	10	…	305	…	72
7050-T7651	550	490	…	10	…	325	…	72
7075-O	230	105	17	14	60	150	…	72
7075-T6, T651	570	505	11	9	150	330	160	72
Alclad 7075-O	220	95	17	…	…	150	…	72
Alclad 7075-T6, T651	525	460	11	…	…	315	…	72
7175-T74	525	455	…	10	135	290	160	72
7178-O	230	105	15	14	…	…	…	72
7178-T6, T651	605	540	10	9	…	…	…	72
7178-T76, T7651	570	505	…	9	…	…	…	71
Alclad 7178-O	220	95	16	…	…	…	…	72
Alclad 7178-T6, T651	560	460	10	…	…	…	…	72
7475-T61	565	490	11	…	…	…	…	70
7475-T651	585	510	…	13	…	…	…	72
7475-T7351	495	420	…	13	…	…	…	72
7475-T761	515	450	12	…	…	…	…	70
7475-T7651	530	460	…	12	…	…	…	72
Alclad 7475-T61	515	455	11	…	…	…	…	70
Alclad 7475-T761	490	420	12	…	…	…	…	70
8176-H24	160	95	15	…	…	70	…	69

Note: Table values not intended for use in design. (a) The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values. (b) Based on 500,000,000 cycles of completely reversed stress using the R.R. Moore type of machine and specimen. (c) Average of tension and compression moduli. Compression modulus is approximately 2% greater than tension modulus. (d) 1350-O wire will have an elongation of approximately 23% in 250 mm. (e) 1350-H19 wire will have an elongation of approximately 1½% in 250 mm. (f) Tempers T361 and T861 formerly were designated T36 and T86, respectively. (g) Based on 10^7 cycles using flexural type testing of sheet specimens. (h) Based on 6.3 mm thick specimen. (i) T7451, although not previously registered, has appeared in literature and in some specifications as T73651.

Table 2 Typical mechanical properties of aluminum alloy castings

		Tension						
Type of casting	Alloy and temper	Ultimate strength, ksi	Yield strength(a), ksi	Elongation in 2 in. or 4D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, ksi	Fatigue, endurance limit(b), ksi	Modulus of elasticity(c), 10^6 ksi
Sand	201.0-T6	65	55	8	130	…	…	…
	201.0-T7	68	60	6	…	…	14	…
	201.0-T43	60	37	17	…	…	…	…
	204.0-T4	45	28	6	…	…	…	…
	A206.0-T4	51	36	7	…	40	…	…
	208.0-F	21	14	3	…	17	11	…
	213.0-F	24	15	2	70	20	9	…
	222.0-O	27	20	1	80	21	9.5	
	222.0-T61	41	40	<0.5	115	32	8.5	10.7
	224.0-T72	55	40	10	123	35	9	10.5

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater. Data taken from various industry handbooks.

Table 2 (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, ksi	Tension: Yield strength(a), ksi	Tension: Elongation in 2 in. or 4D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, ksi	Fatigue, endurance limit(b), ksi	Modulus of elasticity(c), 10^6 ksi
Sand	240.0-F	34	28	1	90	…	…	…
(continued)	242.0-F	31	20	1	…	…	…	10.3
	242.0-O	27	18	1	70	21	8	10.3
	242.0-T571	32	30	1	85	26	11	10.3
	242.0-T61	32	20	…	90–120	…	…	10.3
	242.0-T77	30	23	2	75	24	10.5	10.3
	A242.0-T75	31	…	2	…	…	…	…
	295.0-T4	32	16	9	80	26	7	10.0
	295.0-T6	36	24	5	75	30	7.5	10.0
	295.0-T62	41	32	2	90	33	8	10.0
	295.0-T7	29	16	3	55–85	…	…	10.0
	319-F	27	18	2	70	22	10	10.7
	319.0-T5	30	26	2	80	24	11	10.7
	319.0-T6	36	24	2	80	29	11	10.7
	328.0-F	25	14	1	45–75	…	…	…
	328.0-T6	34	21	1	65–95	…	…	…
	355.0-F	23	12	3	…	…	…	10.2
	355.0-T51	28	23	2	65	22	8	10.2
	355.0-T6	35	25	3	80	28	9	10.2
	355.0-T61	35	35	1	90	31	9.5	10.2
	355.0-T7	38	26	1	85	28	10	10.2
	355.0-T71	35	29	2	75	26	10	10.2
	C355.0-T6	39	29	5	85	…	…	…
	356.0-F	24	18	6	…	…	…	10.5
	356.0-T51	25	20	2	60	20	8	10.5
	356.0-T6	33	24	4	70	26	8.5	10.5
	356.0-T7	34	30	2	75	24	9	10.5
	356.0-T71	28	21	4	60	20	8.5	10.5
	A356.0-F	23	12	6	…	…	…	10.5
	A356.0-T51	26	18	3	…	…	…	10.5
	A356.0-T6	40	30	6	75	…	…	10.5
	A356.0-T71	30	20	3	…	…	…	10.5
	357.0-F	25	13	5	…	…	…	…
	357.0-T51	26	17	3	…	…	…	…
	357.0-T6	50	42	2	…	…	…	…
	357.0-T7	40	34	3	60	…	…	…
	A357.0-T6	46	36	3	85	40	12	…
	359.0-T62	50	42	6	16	…	…	…
	A390.0-F	26	26	<1.0	100	…	…	…
	A390.0-T5	26	26	<1.0	100	…	…	…
	A390.0-T6	40	40	<1.0	140	…	13	…
	A390.0-T7	36	36	<1.0	115	…	…	…
	443.0-F	19	8	8	40	14	8	10.3
	B443.0-F	17	6	3	25–55	…	…	…
	A444.0-F	21	9	9	30–60	…	…	…

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater. Data taken from various industry handbooks.

Table 2 (continued)

		Tension						
Type of casting	Alloy and temper	Ultimate strength, ksi	Yield strength(a), ksi	Elongation in 2 in. or 4D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, ksi	Fatigue, endurance limit(b), ksi	Modulus of elasticity(c), 10^6 ksi
Sand (continued)	A444.0-T4	23	9	12	43	…	…	…
	511.0-F	21	12	3	50	17	8	…
	512.0-F	20	13	2	50	17	9	…
	514.0-F	25	12	9	50	20	7	…
	520.0-T4	48	26	16	75	34	8	…
	535.0-F	35	18	9	60–90	…	…	…
	535.0-T5	35	18	9	60–90	…	…	…
	A535.0-F	36	18	9	65	…	…	…
	707.0-T5	33	22	2	70–100	…	…	…
	707.0-T7	37	30	1	65–95	…	…	…
	710.0-F	32	20	2	60–90	…	…	…
	710.0-T5	32	20	2	60–90	…	…	…
	712.0-F	34	25	4	60–90	…	…	…
	712.0-T5	34	25	4	60–90	…	…	…
	713.0-F	32	22	3	60–90	…	…	…
	713.0-T5	32	22	3	60–90			
	771.0-T5	32	27	3	70–100	…	…	…
	771.0-T52	36	30	2	70–100	…	…	…
	771.0-T53	36	27	2	…	…	…	…
	771.0-T6	42	35	5	75–105	…	…	…
	771.0-T71	48	45	2	105–135	…	…	…
	850.0-T5	20	11	8	45	14	…	10.3
	851.0-T5	20	11	5	45	14	…	10.3
	852.0-T5	27	22	2	65	18	10	10.3
Permanent mold	201.0-T6	65	55	8	130	…	…	…
	201.0-T7	68	60	6	…	…	14	…
	201.0-T43	60	37	17	…	…	…	…
	204.0-T4	48	29	8	…	…	…	…
	A206.0-T4	62	38	17	…	42	…	…
	A206.0-T7	63	50	12	…	37	…	…
	208.0-T6	35	22	2	75–105	…	…	…
	208.0-T7	33	16	3	65–95	…	…	…
	213.0-F	30	24	2	85	24	9.5	…
	222.0-T551	37	35	<0.5	115	30	8.5	10.7
	222.0-T52	35	31	1	100	25	…	10.7
	238.0-F	30	24	2	100	24	…	…
	242.0-T61	47	42	1	110	35	10	10.3
	A249.0-T63	69	60	6	…	…	…	…
	296.0-T7	39	20	5	80	30	9	10.1
	308.0-F	28	16	2	70	22	13	…
	319.0-F	34	19	3	85	24	…	10.7
	319.0-T6	40	27	3	95	…	…	10.7
	324.0-F	30	16	4	70	…	…	…
	324.0-T5	36	26	3	90	…	…	…
	324.0-T62	45	39	3	105	…	…	…

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater. Data taken from various industry handbooks.

Table 2 (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, ksi	Tension: Yield strength(a), ksi	Tension: Elongation in 2 in. or 4D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, ksi	Fatigue, endurance limit(b), ksi	Modulus of elasticity(c), 10^6 ksi
Permanent mold (continued)	332.0-T5	36	28	1	105	…	…	…
	328.0-T6	34	21	1	65–95	…	…	…
	333.0-F	34	19	2	90	27	15	…
	242.0-T571	40	34	1	105	30	10.5	10.3
	333.0-T5	34	25	1	100	27	12	…
	333.0-T6	42	30	2	105	33	15	…
	333.0-T7	37	28	2	90	28	12	…
	336.0-T551	36	28	1	105	28	14	…
	336.0-T65	47	43	1	125	36	…	…
	354.0-T61	48	37	3	…	…	…	…
	354.0-T62	52	42	2	…	…	…	…
	355.0-F	27	15	4	…	…	…	10.2
	355.0-T51	30	24	2	75	24	…	10.2
	355.0-T6	42	27	4	90	34	10	10.2
	355.0-T61	45	40	2	105	36	10	10.2
	355.0-T7	40	30	2	85	30	10	10.2
	355.0-T71	36	31	3	85	27	10	10.2
	C355.0-T6	48	28	8	90	…	…	10.2
	C355.0-T61	46	34	6	100	…	…	10.2
	C355.0-T62	48	37	5	100	…	…	10.2
	356.0-F	26	18	5	…	…	…	10.5
	356.0-T51	27	20	2	…	…	…	10.5
	356.0-T6	38	27	5	80	30	13	10.5
	356.0-T7	32	24	6	70	25	11	10.5
	356.0-T71	25	…	3	60–90	…	…	10.5
	A356.0-F	27	13	8	…	…	…	10.5
	A356.0-T51	29	20	5	…	…	…	10.5
	A356.0-T6	41	30	12	80	…	…	10.5
	357.0-F	28	15	6	…	…	…	…
	357.0-T51	29	21	4	…	…	…	…
	357.0-T6	52	43	5	100	35	13	…
	357.0-T7	38	30	5	70	…	…	…
	A357.0-T6	52	42	5	100	35	15	…
	359.0-T61	48	37	6	…	…	…	…
	359.0-T62	50	42	6	…	…	16	…
	A390.0-F	29	29	<1.0	110	…	…	…
	A390.0-T5	29	29	<1.0	110	…	…	…
	A390.0-T6	45	45	<1.0	145	…	17	…
	A390.0-T7	38	38	<1.0	120	…	15	…
	443.0-F	23	9	10	45	16	8	10.3
	B443.0-F	21	6	6	30–60	…	…	…
	A444.0-F	24	11	13	44	…	…	…
	A444.0-T4	23	10	21	45	16	8	…
	513.0-F	27	16	7	60	22	10	…
	535.0-F	35	18	8	60–90	…	…	…
	705.0-T5	37	17	10	55–75	…	…	…

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater. Data taken from various industry handbooks.

Table 2 (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, ksi	Tension: Yield strength(a), ksi	Tension: Elongation in 2 in. or 4D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, ksi	Fatigue, endurance limit(b), ksi	Modulus of elasticity(c), 10^6 ksi
Permanent mold (continued)	707.0-T7	45	35	3	80–110	…	…	…
	711.0-T1	28	18	7	55–85	…	…	…
	713.0-T5	32	22	4	60–90			
	850.0-T5	23	11	12	45	15	9	10.3
	851.0-T5	20	11	5	45	14	9	10.3
	851.0-T6	18	…	8	…	…	…	10.3
	852.0-T5	32	23	5	70	21	11	10.3
Die cast	360.0-F	44	25	3	75	28	20	10.3
	A360.0-F	46	24	4	75	26	18	10.3
	380.0-F	46	23	3	80	28	20	10.3
	A380.0-F	47	23	4	80	27	20	10.3
	383.0-F	45	22	4	75	…	21	10.3
	384.0-F	48	24	3	85	29	20	…
	390.0-F	40.5	35	<1	…	…	…	…
	B390.0-F	46	36	<1	120	…	20	11.8
	392.0-F	42	39	<1	…	…	…	…
	413.0-F	43	21	3	80	25	19	10.3
	A413.0-F	42	19	4	80	25	19	…
	C443.0-F	33	14	9	65	29	17	10.3
	518.0-F	45	28	5	80	29	20	…

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater. Data taken from various industry handbooks.

Table 2M Typical mechanical properties of aluminum alloy castings (metric)

Type of casting	Alloy and temper	Tension: Ultimate strength, MPa	Tension: Yield strength(a), MPa	Tension: Elongation In 5D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, MPa	Fatigue, endurance limit(b), MPa	Modulus of elasticity(c), 10^6 MPa
Sand	201.0-T6	450	380	8	130	…	…	…
	201.0-T7	470	415	6	…	…	95	…
	201.0-T43	415	255	17	…	…	…	…
	204.0-T4	310	195	6	…	…	…	…
	A206.0-T4	350	250	7	…	275	…	…
	208.0-F	145	655	3	…	115	75	…
	213.0-F	165	105	2	70	140	60	…
	222.0-O	185	140	1	80	145	65	
	222.0-T61	285	275	<0.5	115	220	60	74
	224.0-T72	380	275	10	123	240	60	73
	240.0-F	235	195	1	90	…	…	…
	242.0-F	145	140	1	…	…	…	71
	242.0-O	185	125	1	70	145	55	71
	242.0-T571	220	205	1	85	180	75	71
	242.0-T61	220	140	…	90–120	…	…	71
	242.0-T77	205	160	2	75	165	70	71
	A242.0-T75	215	…	2	…	…	…	…

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater than the tension modulus. Data taken from various industry handbooks.

Table 2M (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, MPa	Tension: Yield strength(a), MPa	Tension: Elongation In 5D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, MPa	Fatigue, endurance limit(b), MPa	Modulus of elasticity(c), 10^6 MPa
Sand	295.0-T4	220	110	9	80	180	50	69
(continued)	295.0-T6	250	165	5	75	205	50	69
	295.0-T62	285	220	2	90	230	55	69
	295.0-T7	200	110	3	55–85	…	…	69
	319-F	185	125	2	70	150	70	74
	319.0-T5	205	180	2	80	165	75	74
	319.0-T6	250	165	2	80	200	75	74
	328.0-F	170	95	1	45–75	…	…	…
	328.0-T6	235	145	1	65–95	…	…	…
	355.0-F	160	85	3	…	…	…	70
	355.0-T51	195	160	2	65	150	55	70
	355.0-T6	240	170	3	80	195	60	70
	355.0-T61	240	240	1	90	215	65	70
	355.0-T7	260	180	1	85	195	70	70
	355.0-T71	240	200	2	75	180	70	70
	C355.0-T6	270	200	5	85	…	…	…
	356.0-F	165	125	6	…	…	…	73
	356.0-T51	170	140	2	60	140	55	73
	356.0-T6	230	135	4	70	180	60	73
	356.0-T7	235	205	2	75	165	60	73
	356.0-T71	195	145	4	60	140	60	73
	A356.0-F	160	85	6	…	…	…	73
	A356.0-T51	180	125	3	…	…	…	73
	A356.0-T6	275	205	6	75	…	…	73
	A356.0-T71	205	140	3	…	…	…	73
	357.0-F	170	90	5	…	…	…	…
	357.0-T51	180	115	3	…	…	…	…
	357.0-T6	345	295	2	…	…	…	…
	357.0-T7	275	235	3	60	…	…	…
	A357.0-T6	315	250	3	85	275	85	…
	359.0-T62	345	290	6	16	…	…	…
	A390.0-F	180	180	<1.0	100	…	…	…
	A390.0-T5	180	180	<1.0	100	…	…	…
	A390.0-T6	275	275	<1.0	140	…	90	…
	A390.0-T7	250	250	<1.0	115	…	…	…
	443.0-F	130	55	8	40	95	55	71
	B443.0-F	115	40	3	25–55	…	…	…
	A444.0-F	145	60	9	30–60	…	…	…
	A444.0-T4	23	60	12	43	…	…	…
	511.0-F	145	85	3	50	115	55	…
	512.0-F	140	90	2	50	115	60	…
	514.0-F	170	85	9	50	140	50	…
	520.0-T4	330	180	16	75	235	55	…
	535.0-F	240	125	9	60–90	…	…	…
	535.0-T5	240	125	9	60–90	…	…	…
	A535.0-F	250	125	9	65	…	…	…

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater than the tension modulus. Data taken from various industry handbooks.

Table 2M (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, MPa	Tension: Yield strength(a), MPa	Tension: Elongation In 5D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, MPa	Fatigue, endurance limit(b), MPa	Modulus of elasticity(c), 10^6 MPa
Sand (continued)	707.0-T5	230	150	2	70–100	…	…	…
	707.0-T7	255	205	1	65–95	…	…	…
	710.0-F	220	140	2	60–90	…	…	…
	710.0-T5	220	140	2	60–90	…	…	…
	712.0-F	235	170	4	60–90	…	…	…
	712.0-T5	235	170	4	60–90	…	…	…
	713.0-F	220	150	3	60–90	…	…	…
	713.0-T5	220	150	3	60–90			
	771.0-T5	220	185	3	70–100	…	…	…
	771.0-T52	250	205	2	70–100	…	…	…
	771.0-T53	250	185	2	…	…	…	…
	771.0-T6	290	240	5	75–105	…	…	…
	771.0-T71	330	310	2	105–135	…	…	…
	850.0-T5	140	75	8	45	95	…	71
	851.0-T5	140	75	5	45	95	…	71
	852.0-T5	185	150	2	65	125	60	71
Permanent mold	201.0-T6	450	380	8	130	…	…	…
	201.0-T7	470	415	6	…	…	95	…
	201.0-T43	415	255	17	…	…	…	…
	204.0-T4	330	200	8	…	…	…	…
	A206.0-T4	430	260	17	…	290	…	…
	A206.0-T7	435	345	12	…	255	…	…
	208.0-T6	240	150	2	75–105	…	…	…
	208.0-T7	230	110	3	65–95	…	…	…
	213.0-F	205	165	2	85	165	65	…
	222.0-T551	255	240	<0.5	115	205	60	74
	222.0-T52	240	215	1	100	170	…	74
	238.0-F	205	165	2	100	165	…	…
	242.0-T571	275	235	1	105	205	70	74
	242.0-T61	325	290	1	110	450	70	74
	A249.0-T63	475	415	6	…	…	…	…
	296.0-T7	270	140	5	80	205	60	70
	308.0-F	195	110	2	70	150	90	…
	319.0-F	235	130	3	85	165	…	74
	319.0-T6	275	185	3	95	…	…	74
	324.0-F	205	110	4	70	…	…	…
	324.0-T5	250	180	3	90	…	…	…
	324.0-T62	310	270	3	105	…	…	…
	332.0-T5	250	195	1	105	…	…	…
	328.0-T6	235	145	1	65–95	…	…	…
	333.0-F	235	130	2	90	185	105	…
	333.0-T5	235	170	1	100	185	85	…
	333.0-T6	290	205	2	105	230	105	…
	333.0-T7	255	195	2	90	195	85	…
	336.0-T551	250	193	1	105	193	95	…

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater than the tension modulus. Data taken from various industry handbooks.

Table 2M (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, MPa	Tension: Yield strength(a), MPa	Tension: Elongation In 5D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, MPa	Fatigue, endurance limit(b), MPa	Modulus of elasticity(c), 10^6 MPa
Permanent mold (continued)	336.0-T65	325	295	1	125	250	…	…
	354.0-T61	330	255	3	…	…	…	…
	354.0-T62	360	290	2	…	…	…	…
	355.0-F	185	105	4	…	…	…	70
	355.0-T51	205	165	2	75	165	…	70
	355.0-T6	290	185	4	90	235	70	70
	355.0-T61	310	275	2	105	250	70	70
	355.0-T7	275	205	2	85	205	70	70
	355.0-T71	250	215	3	85	185	70	70
	C355.0-T6	330	195	8	90	…	…	70
	C355.0-T61	315	235	6	100	…	…	70
	C355.0-T62	330	255	5	100	…	…	70
	356.0-F	180	125	5	…	…	…	73
	356.0-T51	185	140	2	…	…	…	73
	356.0-T6	260	185	5	80	205	90	73
	356.0-T7	220	165	6	70	170	75	73
	356.0-T71	170	…	3	60–90	…	…	73
	A356.0-F	165	90	8	…	…	…	73
	A356.0-T51	200	140	5	…	…	…	73
	A356.0-T6	285	205	12	80	…	…	73
	357.0-F	195	105	6	…	…	…	…
	357.0-T51	200	145	4	…	…	…	…
	357.0-T6	360	295	5	100	240	90	…
	357.0-T7	260	205	5	70	…	…	…
	A357.0-T6	360	290	5	100	240	105	…
	359.0-T61	330	255	6	…	…	…	…
	359.0-T62	345	290	6	…	…	110	…
	A390.0-F	200	200	<1.0	110	…	…	…
	A390.0-T5	200	200	<1.0	110	…	…	…
	A390.0-T6	310	310	<1.0	145	…	115	…
	A390.0-T7	260	260	<1.0	120	…	105	…
	443.0-F	160	60	10	45	110	55	71
	B443.0-F	145	40	6	30–60	…	…	…
	A444.0-F	165	75	13	44	…	…	…
	A444.0-T4	160	70	21	45	110	55	…
	513.0-F	185	110	7	60	150	70	…
	535.0-F	240	125	8	60–90	…	…	…
	705.0-T5	255	115	10	55–75	…	…	…
	707.0-T7	310	240	3	80–110	…	…	…
	711.0-T1	195	125	7	55–85	…	…	…
	713.0-T5	220	150	4	60–90			
	850.0-T5	160	75	12	45	105	60	71
	851.0-T5	140	75	5	45	95	60	71
	851.0-T6	125	…	8	…	…	…	71
	852.0-T5	220	160	5	70	145	75	71

(continued)

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater than the tension modulus. Data taken from various industry handbooks.

Table 2M (continued)

Type of casting	Alloy and temper	Tension: Ultimate strength, MPa	Tension: Yield strength(a), MPa	Tension: Elongation In 5D, %	Hardness, Brinell No., 500kg/10mm	Shear, ultimate strength, MPa	Fatigue, endurance limit(b), MPa	Modulus of elasticity(c), 10^6 MPa
Die cast	360.0-F	305	170	3	75	195	140	71
	A360.0-F	315	165	4	75	180	124	71
	380.0-F	315	160	3	80	195	140	71
	A380.0-F	325	160	4	80	185	140	71
	383.0-F	310	150	4	75	…	145	71
	384.0-F	330	165	3	85	200	140	…
	390.0-F	280	240	<1	…	…	…	…
	B390.0-F	315	250	<1	120	…	140	81
	392.0-F	290	270	<1	…	…	…	…
	413.0-F	295	145	3	80	170	130	71
	A413.0-F	290	130	4	80	170	130	…
	C443.0-F	230	95	9	65	200	115	71
	518.0-F	310	193	5	80	200	140	…

Values are representative of separately cast test bars, not of specimens taken from commercial castings. (a) For tensile yield strengths, offset = 0.2%. (b) Based on 500,000,000 cycles of completely reversed stress using R.R. Moore type of machines and specimens. (c) Average of tension and compression moduli; compressive modulus is nominally approximately 2% greater than the tension modulus. Data taken from various industry handbooks.

Review of the Basic Tempers for Wrought Alloys

The temper designation always is presented immediately following the alloy designation (Chapter 3), with a hyphen between the two (e.g., 2014-T6). Generally, the temper designation consists of a capital letter indicating the major class of fabrication treatment(s) used, plus one or more numbers providing more specific information about how the processing was carried out. These designations are not intended to provide the exact practices (times, temperatures, reductions), but rather the general combinations of practices followed.

As review, recall that the first character in the temper designation (a capital letter, F, O, H, W, or T) indicates the general class of treatment. Information on each of these classes of designation and a few examples of each are provided by the following descriptions:

- *F, as fabricated:* This designation is used for wrought or cast products made by some shaping process such as rolling, extrusion, forging, drawing, or casting where there is no special control over the thermal conditions during working or the strain-hardening processes to achieve specific properties. There are no specified limits on mechanical properties of any wrought F temper product. Except in the case of cast parts, which may be in the final configuration, most F temper products are "semifinished" products that will be used in some subsequent shaping, finishing, or thermal process to achieve other finished forms or tempers. For example, 2014-F designates an as-fabricated product form of alloy 2014; it may represent any production process or product form and may be used for products that have been rolled, extruded, forged, or any combination of those processes.

- *O, annealed:* This designation is used for wrought or cast products made by some shaping process such as rolling, extrusion, forging, drawing, or casting, and which product at some point in the process has been annealed (i.e., given a high-temperature recrystallization treatment, sufficient to remove the effects of any prior working or thermal treatments and usually resulting in complete recrystallization of the material). Annealing treatments are used to achieve the lowest-strength condition for the particular alloy involved. The primary reason for using such a treatment on wrought alloys generally is to maximize subsequent workability or increase toughness and ductility to a maximum. For example:

  a. 2014-O designates any product form of 2014 whose most recent treatment has been holding at a high temperature (~410 °C, or ~770 °F) for 2 to 3 h, slow cooling to ~260 °C (~500 °F) and then cooling at an uncontrolled rate to room temperature. For this alloy, the treatment would normally be given to increase ease of subsequent working while completely removing any effects of prior treatments.
  b. 5083-O designates any product form of 5083 whose most recent treatment has been heating up to a high temperature (~345 °C, ~650 °F) and then cooled at an uncontrolled rate to room temperature. For this alloy, the treatment would normally be given to increase toughness and ductility for its use in critical structural applications such as liquefied natural gas tanks.

- *H, strain hardened:* This designation is used for non-heat-treatable wrought alloys that have had their strength increased by strain hardening (e.g., rolling, drawing) usually at room temperature. This designation may, but does not necessarily, also apply to products that have been given supplementary thermal treatments to achieve some stabilization in strength level, since a number of aluminum alloys will gradually soften slightly with time after cold working. The H is always followed by two or more digits, the purpose of which is to indicate the approximate amount of cold work and the nature of any thermal treatments that followed. The variety of subsequent designations available is discussed later, so the examples focus more on the H designation itself at this point. For example:

  a. 1350-H12 indicates that sheet, plate, rod, or wire of alloy 1350 has been cold worked to increase its strength. The H12 combination indicates approximately 20 to 25% cold reduction without any subsequent thermal treatments (other variations are discussed later).

b. 5005-H18 indicates that sheet (the only product available in that temper) of alloy 5005 has been cold rolled to increase its strength. The H18 combination indicates a large amount of cold work, normally around 75 to 80% without any subsequent thermal treatment.

- *W, solution heat treated:* This designation is rather limited in its use and applies only to alloys that age naturally and spontaneously after solution heat treating (holding at high temperature followed by quenching or relatively rapid cooling to room temperature). Digits may be added to characterize more specifically the elapsed time since the cooling took place; this is not necessary and is of limited value since the time may continue to increase, but it is often helpful in whatever subsequent treatments are to be applied to know that elapsed time and the effects of the elapsed time on response to subsequent working or thermal exposure. As with the F temper, there are no published standard property limits for wrought alloys associated with the W temper, and it is rarely a "finished" temper (i.e., sold in that temper; it is always an "in-process" temper, to be followed by subsequent mechanical or thermal treatments). For example:

  a. 6061-W indicates a semifinished product of 6061 that has been heat treated and quenched by standard procedures but not yet given any subsequent mechanical or thermal treatment. Alloy 6061 naturally ages following a quench from a heat treatment, and so the yield strength, in particular, of this material gradually increases with time until some treatment that will stabilize its properties is given, such as artificial aging for precipitation hardening.
  b. 6061-W½hr. indicates the same material as in the preceding example, except that a time (½ h after quenching) has been added to define the time lapse and perhaps permit some estimate of the effect on strength (assuming that aging rate data are accessible).

- *T, thermally treated to produce stable tempers other than F, O, or H:* The T designation is the most widely used for heat treated alloys, and applies to any product form of any heat treatable alloy that has been given a solution heat treatment followed by a suitable quench and either natural (i.e., in air) or artificial (i.e., in a furnace) aging. The T always is followed by one or more digits that define in general terms the subsequent treatments; these will be discussed in more detail later, and so the following examples focus on the T designation. For example:

  a. 2024-T4 indicates a 2024 product that has been solution heat treated, quenched, and naturally aged by standard commercial processes to a stable condition. Since this alloy achieves a commercially useful level of strength coupled with a high toughness in the T4 condition, this may well be the final temper designation.

b. 2014-T4 indicates an alloy 2014 product that has been solution heat treated and naturally aged to a stable condition preparatory to artificially aging it for precipitation hardening to the T6 temper. Alloy 2014 does not have a useful combination of strength, toughness, and corrosion resistance in the T4 condition, so it is almost always subsequently given a precipitation hardening treatment.

Subdivisions of the Basic Tempers

As just indicated, most of the basic temper designations listed previously are used with additional numerical digits to define the practices more completely. It is useful to review these additional digits and the resulting complete designations in considerable detail to obtain the best understanding of their meanings.

The H and T are the most frequently used tempers and are, therefore, discussed sequentially. The F, O, and W designations are generally used alone and provide the complete description, and thus there is little to say about them except for one minor variation of the O temper that is covered later.

Subdivisions of the H Temper for Non-Heat-Treatable Alloys. The H temper indicates that the alloy involved has been cold worked by strain hardening. The H always is followed by at least two numbers:

- The first number after the H tells whether the strain-hardened alloy has been thermally treated and, if so, by what procedure.
- The second number indicates approximately how much the alloy was strain hardened (i.e., the approximate percentage of cold reduction).
- Any subsequent numbers define special practices, variations of the normal indicated by the first two numbers.

The first number, indicating variations in thermal treatments following cold work, may be one of four possibilities:

- H1 indicates that processing was limited to strain hardening; there was no subsequent thermal treatment.
- H2 indicates strain hardening followed by a partial high-temperature recrystallization thermal treatment (i.e., a partial anneal) to take the properties back to some stable level less than those achieved by the cold working. When this temper is used, the alloy has intentionally been strain hardened more than the desired amount and then partially annealed back to achieve a specific level of strength.
- H3 indicates strain hardening followed by a thermal stabilization treatment (i.e., holding at a modestly elevated temperature to permit the properties to stabilize and avoid time-dependent age softening, to

which certain alloys, especially of the 5*xxx* series, are prone). This also may be accomplished by the heat applied during a subsequent forming.

- H4 indicates strain hardening followed by some thermal operation such as paint curing or lacquering in which the heat applied during this processing effectively reduces the degree of hardening remaining in the alloy and provides some stabilization to the final properties. It is useful to note that there are no unique property limits associated with H4X tempers; rather, the property limits associated with the comparable H2X or H3X tempers are used.

As noted earlier, these H1, H2, H3, and H4 designations always are followed by a second number that indicates the approximate amount of cold work.

Examples of the application of these designations include:

- *3003-H12:* Strain hardened approximately 25%; no other treatment (i.e., meets properties for H12 temper)
- *3005-H26:* Strain hardened and partial annealed to effective strain hardening of about 75% (i.e., meets properties for H26 temper)
- *5052-H32:* Strain hardened and stabilized to effective strain hardening of about 25% (i.e., meets properties for H32 temper)
- *5052-H42:* Strain hardened and given some finishing treatment that provides effective strain hardening of approximately 25% (i.e., meets properties for H42/H22 temper)

As indicated by these examples, the digit following H1, H2, H3, or H4, indicates the effective degree of strain hardening remaining in the metal following the sequence of operations indicated by the first digit. In other words:

- *H1X temper:* The X represents the actual amount of strain hardening given the alloy; no thermal treatment has been given to reduce the effective work remaining in the metal.
- *H2X temper:* The X represents the effective cold work remaining after the metal has been cold worked beyond the final level desired, and partial annealed back.
- *H3X and H4X tempers:* The X indicates the effective cold work remaining in the metal following cold working and the intermediate temperature stabilization treatment or the thermal exposure involved in the subsequent forming, painting, or lacquering processes.

The second numerical digits have both a technical definition according to the Aluminum Association and a "schematic," or approximate, definition as used in the trade. According to the Aluminum Association rules, the second digit is defined based upon the minimum value of the ultimate tensile strength of the material. In other words, the level of strength achieved is compared with the standard limits published for the various alloys, and the level most nearly met is used as the appropriate temper. Therefore, the hardest temper normally produced is indicated by adding the numeral 8 (i.e., HX8), and the standard increase in strength from the annealed (no cold work) to the HX8 temper is judged by the values in Table 3.

Tempers between O and HX8 are defined as follows:

- A degree of cold work equal to approximately one-half that for the HX8 temper is indicated by the HX4 temper and would be indicated by an increase in tensile strength of one-half the value in the second column of Table 3 for the appropriate level in the annealed temper. As an example, the minimum tensile strength of 1100-O sheet and plate is 11 ksi, so the tensile strength limit for 1100-H14 is 11 ksi plus ½ × 10 (from Table 3) or 16 ksi. In the corresponding metric example, the minimum tensile strength of 1100-O sheet and plate is 75 MPa, so the tensile strength of 1100-H14 is 75 plus ½ × 75 (from Table 3M) or 112.5 MPa, rounded to 110 MPa. It is appropriate to note that the rules in Tables 3 and 3M were not used in the early days of the aluminum

Table 3 Range of values per HX8 temper

Minimum tensile strength in annealed temper, ksi	Increase in tensile strength to HX8 temper, ksi
Up to 6	8
7 to 9	9
10 to 12	10
13 to 15	11
16 to 18	12
19 to 24	13
25 to 30	14
31 to 36	15
37 to 42	16
43 and over	17

Table 3M Tensile strengths of HX8 tempers (metric)

Minimum tensile strength in annealed temper, MPa	Increase in tensile strength to HX8 temper, MPa
Up to 40	55
45–60	62
65–80	69
85–100	76
105–120	83
125–160	90
165–200	97
205–240	103
245–280	110
285–320	115
296 and over	120

industry, and so there are exceptions among long-established property values.

- A degree of cold work halfway between the O temper and the HX4 temper is indicated by the HX2 temper; a degree of cold work halfway between HX4 and HX8 is the HX6 temper. Following the example given for 1100, the respective tensile strength limits would be 14 ksi for H12 and 19 ksi for H16, respectively (the 0.5 ksi increments being rounded up). As a metric example for 1100, the respective tensile strength limit would be 130 MPa for H16, midway between the H14 and H18 values.
- The numbers 1, 3, 5, and 7 similarly designate tempers intermediate between those just listed. In practice, these designations are seldom used; when they are, as in the case of 5657-H25, it is usually for some special product to indicate a specific treatment given to enhance some specific property (brightness, in the example given). The odd-numbered tempers also are used for pattern sheet temper designations, as described later.
- The numeral 9 is used to indicate tempers with properties exceeding those of HX8 by 14 MPa (2 ksi) or more. This temper is achieved by cold rolling sheet to very small thicknesses, usually only a few thousandths of an inch. This designation also is used only for special products; the most important example is 3004-H19 sheet for can stock (i.e., starting stock for the production of aluminum cans).

Some additional examples of two-digit H tempers that illustrate use of the first and second digits include the following:

- *3003-H14:* The "1" indicates that the material has been strain hardened and given no subsequent processing; the "4" indicates that the amount of strain hardening was about 50% of the level for the H18, or "full-hard" temper.
- *5657-H26:* The "2" indicates that the alloy has been strain hardened a relatively large amount and then partially annealed back to the desired level of effective cold work; the "6" indicates that the effective final level of cold work was about 80% of that of the full-hard H18 temper.
- *5086-H32:* The "3" indicates that the alloy has been strain hardened and stabilized; the "2" indicates that the degree of strain hardening was about 25% of the level for the H38 temper. Applications include sheet, plate, and drawn tube.

Three-digit H Tempers. The final group of subdivisions of the H tempers that needs to be recognized involves the use of a third numeric digit for the H tempers. A third digit, such as HXX1, indicates a variation in a two-digit temper. Differences may be in such things as the degree of control of mechanical properties or a special finish; in such instances, however, the differences are not usually very great.

An excellent example of the use of a third digit of an H temper designation is the series used for embossed sheet (i.e., sheet that, after other processing, has been finish rolled, with rolls having specific patterns on the surface to impart the reverse of that pattern onto the surface of the sheet). Such products also are known as pattern sheet and have the specific set of temper designations listed in Table 4 associated with them. These designations follow the same rules just described but have the number 4 added to the standard designation describing its processing up to the final pattern rolling operation.

Another example of a three-digit H temper indicating treatment to impart special properties is the H116 temper (e.g., 5086-H116), which has been given a unique combination of cold work and thermal treatment to make it especially resistant to the corrosive effects of water and high-humidity environments and to minimize the possible effects of stress-corrosion sensitization from high-temperature exposure.

Two other examples of a three-digit H temper cover the special cases of products having an uncontrolled amount of cold work but still being required to meet minimum specifications (i.e., the H111 and H112 tempers):

- *Alloy 5086-H111:* This temper recognizes that the alloy underwent some amount of cold strain hardening after annealing but not enough for it to qualify as an H11 or H12 temper. The H111 temper is usually applied to extruded shapes that must be straightened after annealing to meet straightness tolerances, but for which the amount of strain is not controlled beyond a very modest amount. There are mechanical property limits indicative of the modest cold work.
- *Alloy 5086-H112:* In this instance, the product has been hot worked enough that it has acquired some added strength that is reflected in the mechanical property limits. The product has not been subsequently cold worked or annealed but retains the effective strain hardening imparted by the hot work. Applications of this alloy include sheet and plate, extruded tube, and extruded rod, wire, bar, and shapes.

Table 4 Three-digit temper designations for aluminum pattern sheet

Pattern or embossed sheet	Fabricated from
H114	O temper
H124, H224, H324	H11, H21, H31 temper, respectively
H134, H234, H334	H12, H22, H32 temper, respectively
H144, H244, H344	H13, H23, H33 temper, respectively
H154, H254, H354	H14, H24, H34 temper, respectively
H164, H264, H364	H15, H25, H35 temper, respectively
H174, H274, H374	H16, H26, H36 temper, respectively
H184, H284, H384	H17, H27, H37 temper, respectively
H194, H294, H394	H18, H28, H38 temper, respectively
H195, H295, H395	H19, H29, H39 temper, respectively

Subdivisions of the T Temper for Heat Treatable Alloys. The T tempers for heat treatable alloys may have from one to five digits following the T, and there are many more possible combinations than for the H tempers. The first digit after the T always indicates the basic type of treatment, and the second to fifth, if they are used, indicate whether the product was stress relieved and, if so, how it was stress relieved, and whether any other special treatments were given.

The first digit after the T may be any of the following:

- *T1:* Indicates that the alloy has been cooled directly from some high-temperature hot-working process such as rolling or extrusion and then naturally aged to a stable condition. As a result, it has received an "effective heat treatment," but it has not received any other processing such as cold work that is recognized by special mechanical property limits. This temper is not widely used because, among other things, the corrosion resistance of the material may not be as good as with other combinations of treatments.
- *T2:* Indicates that the alloy has been cooled from some high-temperature hot-working process such as rolling or extrusion and then cold worked before being naturally aged to a stable condition. Here again, the alloy has received an "effective heat treatment" as a result of the high-temperature treatment, but in this case, it has been cold worked sufficiently to increase its strength. This temper, as the T1, is not widely used because of limitations in certain characteristics compared with those given other combinations of treatments described as follows:
- *T3:* Indicates the alloy has been given a solution heat treatment following hot working, quenching, cold working, and being naturally aged to a stable condition. This temper, like T4, T6, T7, and T8, indicates the use of a specific solution heat treatment (i.e., holding in a furnace at a sufficiently high temperature for the important alloying elements to go into solution, where they are retained upon quenching and provide a source of precipitation-hardening constituents). The amount of cold work is controlled to provide specific amounts of strain hardening with a commensurate increase in strength. This is a widely used temper type for 2*xxx* series alloys such as 2024, which naturally age efficiently following cold work.
- *T4:* Indicates the alloy has been given a solution heat treatment and, without any cold work, naturally aged to a stable condition. This temper also is rather widely used for the 2*xxx* alloys.
- *T5:* Indicates the alloy has been cooled from a high-temperature shaping process, usually extrusion, and then, without any intermediate cold work, is artificially aged. The artificial aging consists of holding at a sufficiently high temperature and sufficiently long time (e.g., 8 h at 175 °C, or 350 °F, or 24 h at 120 °C, or 250 °F) to permit precipitation

hardening to take place. If there is any straightening or flattening to meet dimensional tolerances, it is not sufficient to be recognized with higher mechanical property limits.

- *T6:* Indicates the alloy has been solution heat treated and, without any significant cold working, artificially aged to achieve precipitation hardening. If there is any straightening or flattening to meet dimensional tolerances, it is not sufficient to be recognized with higher mechanical property limits.
- *T7:* Indicates the alloy has been solution heat treated and, without any significant cold working, aged in a furnace to an overaged (i.e., past peak strength) condition (also sometimes referred to as *stabilized*). This treatment generally is used for the 7*xxx* series alloys (e.g., 7075-T73 or T76) to improve their resistance to either stress-corrosion cracking (SCC) (T73) or to exfoliation corrosion (T76) attack; the T73 is the more severely overaged condition (see the subsequent section "Tempers Designating Special Corrosion-Resistant Tempers").
- *T8:* Indicates the alloy has been solution heat treated, cold worked for strain hardening, and then artificially aged to achieve precipitation hardening. The material also may have been cold worked primarily to meet dimensional or stress relief requirements, but if the T8 temper is used, the amount of cold work is sufficient to be recognized by higher mechanical property limits. This temper primarily is used for the 2*xxx* alloys (e.g., 2024-T81 sheet).
- *T9:* Indicates the alloy has been solution heat treated, artificially aged to achieve precipitation hardening, and then cold worked to improve its strength. This temper is not widely used but is applied to the 2*xxx* series in some cases.
- *T10:* Indicates the alloy has been cooled from a high-temperature shaping process such as extrusion, cold worked, and then artificially aged for precipitation hardening. This temper rarely is used because there are no current commercial applications for it.

In all of the T-type tempers just described, solution heat treatment is achieved by heating semifinished or finished products to a suitable temperature, holding them at that temperature long enough to allow constituents to go into solution, and cooling them rapidly enough to hold the constituents in solution so that they may be the basis of precipitation hardening upon natural (i.e., room temperature) or artificial (i.e., in a furnace) aging.

Adding Additional Digits to the T1 to T10 Tempers. Additional digits, the first of which shall not be zero, may be added to designations T1 to T10 to indicate a variation in treatment that significantly alters the product characteristics that are or would be obtained using the basic treatment. There is no standard listing of all such possible variations, so the best way to illustrate and understand this usage better is to examine the major examples, as in the following sections that cover:

- Stress relief
- Heat treatment by user
- Variations in heat treatment procedures
- Variations in quenching procedures
- Addition of cold work before or after aging
- Special practices for unique properties

Tempers Designating Residual Stress Relief of Heat Treated Products

Two major classes of mechanical cold work are widely used by the aluminum industry to reduce the level of internal residual stresses in aluminum semifinished products resulting from prior heat treatment:

- Stress relief by *stretching*, usually in the range of 1 or 1½ to 3%, applied to rolled plate and rod, to extruded shapes, and occasionally to die or ring forgings; this treatment is designated by:
  a. TX51 for plate, rolled or cold-finished rod, and die or ring forgings
  b. TX510 or TX511 for all extruded shapes, where the extra digit 0 indicates stretching only, and the extra digit 1 indicates stretching combined with additional straightening such as twisting

- Stress relief by 1 to 5% *compressive cold work,* usually applied to hand forgings and die forgings. This treatment is indicated by the TX52 temper designation.

Sometimes these two methods of stress relief are used in combination (i.e., both stretching and compressing), indicated by the use of the TX54 temper designation.

In all of these cases, the cold work for stress relief is carried out following quenching from the solution heat treatment and before artificial aging.

While these temper designations for stress-relieved products have their widest use for heat treated products with T-type tempers, it should be noted that all of these designations may be applied to the W-type tempers as well.

To illustrate the use of these designations for stress-relieved tempers, consider the following examples:

- *Alloy 7075-T651 plate:* Basic temper is T6, indicating solution heat treatment, quenching, and artificial aging; product has been stress relieved: T65; stress relief provided by stretching ½ to 2%: T651
- *Alloy 7075-T6510 extruded tube:* Basic temper is T6, indicating solution heat treatment, quenching, and artificial aging; product has

been stress relieved: T65; stress relief provided by stretching ½ to 3%, without any additional twisting or mechanical straightening: T6510

- *Alloy 7075-T6511 extruded tube:* Basic temper is T6, indicating solution heat treatment, quenching, and artificial aging; product has been stress relieved: T65; stress relief provided by stretching ½ to 3% and twisting for straightness: T6511
- *Alloy 2014-T652 hand forging:* Basic temper is T6; product has been stress relieved: T65; stress relief provided by compression 1 to 5%
- *Alloy 7050-T654 die forging:* Basic temper is T6, indicating solution heat treatment, quenching, and artificial aging; product has been stress relieved: T65; stress relief has been provided by a combination of stretching and restriking in cold dies: T654

Temper Designations Identifying Modifications in Quenching

Another means of minimizing residual stresses besides cold work following quenching is to quench the product in boiling water or oil following holding in a furnace for heat treatment, in contrast to the cold-water quench known to impart much of the residual stress. A special temper designation is used to designate such treatment−the addition of the digit 1.

Thus, for some wrought alloys in T4 (solution heat treated and naturally aged), T6 (solution heat treated and artificially aged), and T7 (solution heat treated and overaged/stabilized) conditions, a descriptive digit 1 is added to the regular temper designation to indicate a change from the normal quenching procedure. By itself, the "1" indicates a boiling water quench. A second digit may be used to indicate some specialized variation of that quench, for example:

- *Alloy 2014-T61 forging:* Basic temper is T6 temper, indicating solution heat treatment, quenching, and artificial aging. Material was quenched in boiling water following the solution heat treatment to minimize residual stresses: T61.
- *Alloy 2014-T611 forging:* Basic temper is T6 temper, indicating solution treat treatment, quenching, and artificial aging. Material was quenched in a special way following the solution heat treatment to minimize residual stresses: T61. Quench medium was adjusted to give property level between T6 and T61 tempers: T611.
- *Alloy 2014-T6151 plate:* Basic temper is T6 temper, indicating solution treat treatment, quenching, and artificial aging. Material was quenched in boiling water following the solution heat treatment: T61. Plate was subsequently stretched ½ to 3% for additional stress relief: T6151.

Designations Indicating Heat Treatment by User

Most temper designations are applied by the producer of the semifinished or finished products, and so the producer is in a position to ensure that the specifications for strength and dimensional tolerances are met when parts are purchased by a customer who then performs some other shaping or machining procedure before the part is heat treated. However, the original producer no longer has any control over the degree to which the required final specifications are met. Therefore, special temper designations have been developed to cover the condition when the final heat treatment and meeting of property specifications is the responsibility of the customer rather than the original producer. These are the TX2 tempers.

It is important to note that the TX2 temper is the proper one to use any time a customer or vendor rather than the original producer heat treats a product. An independent heat treater, regardless of how reliable, cannot be assumed to apply one of the standard tempers described heretofore to a product in the same manner and with the same reliability as the original producer. It is important, therefore, to make clear that the responsibility for meeting mechanical properties rests with the customer rather than the producer.

The TX2 descriptor is applied to wrought products heat treated from any temper by the user of the product or the vendor (e.g., an aircraft company or its heat treating service) rather than the original material producer (e.g., an aluminum company). The TX2 designation is used in combination with tempers such as T4, T6, T73, or T76, indicative of other aspects of the processing (e.g., T42, T62, T732, or T762). In practice, the TX2 temper is used most often for wrought products that have been heat treated from the O or F temper to demonstrate response to heat treatment.

Aluminum producer mills are almost always starting with freshly produced F temper materials and are accustomed to paying close attention to the consistency in processing operations needed to ensure meeting materials specifications. These procedures provide the mill with a consistent statistical base of operations and good knowledge of allowable variations in aging times and temperatures for the semifinished parts.

There are times when the mechanical property limits for the standard temper and the TX2 version of that temper (e.g., T6 and T62) differ. This is because of the difference in controls of processing variables in the producer's operations compared with those in customers' and their vendors' plants, and because customers and their vendors may not be able to do standard stress relief treatments such as those done by producers.

On the other hand, structural engineers, such as those in the aerospace industry, may use tensile strength and yield strength values based on their extensive statistical analyses of finished parts, which become the basis of their design values. These values may differ from producer-developed specification limits.

Differences in producer and user testing requirements also must be taken into account. The producer guarantees tensile, yield, and elongation properties of each heat or lot of material to be delivered by the producer.

Each heat or lot is tensile tested to be sure that property requirements are met. Questionable material is either reprocessed or rejected. By comparison, the end-user heat treater of the material may or may not be asked by the customer to tensile test each lot. Typically, the heat treater relies solely on the results of hardness and conductivity tests to determine whether heat treatment is done correctly. There is an assumption made by the customer that the material would pass tensile test minimums if tested. For example, for 7075-T62 die forging, the basic temper is T6, indicating solution heat treatment, quenching, and artificial aging. The added digit 2 in T62 indicates that the heat treatment and aging were carried out by other than the original producer of the forging (i.e., by the user or a contractor of the user).

Tempers Identifying Additional Cold Work between Quenching and Aging

To obtain particularly high strengths in aluminum alloy sheet in the heat treated condition, alloys (notably 2024) sometimes are given additional cold work between solution heat treatment and artificial aging beyond that which might be used simply for straightening or stress relief. These are indicated by variations of the usual tempers for sheet that is simply straightened or flattened after heat treatment, such as the T3 and T81 tempers of 2024. With the additional cold work, the temper designations are T361 and T861, respectively:

- *2024-T361 sheet:* Basic temper is T3, indicating solution heat treatment followed by cold work. The amount of cold work is significantly beyond that for straightening or flattening (T3 temper): T361.
- *2024-T861 sheet:* Basic temper is T8, indicating solution heat treatment, cold work, and artificial aging. The amount of cold work is significantly beyond that for straightening or flattening (T81 temper): T861.

Tempers Identifying Additional Cold Work Following Aging

Another means sometimes used to gain added strength in aluminum alloy products is the addition of stretching or drawing following the heat treatment and artificial aging. This is indicated by the use of the T9 temper. It is used only for a few standard products such as screw machine stock and wire. The T9 may be followed by other numbers indicating special modifications of the treatment:

- *6262-T9 rod:* Basic temper is T9, indicating solution heat treatment, quenching, and artificial aging followed by cold work.
- *6061-T94 wire:* Basic temper is T9, indicating solution heat treatment, quenching, and artificial aging followed by cold work. Modification given to ensure meeting requirements for product: T94

Tempers Designating Special Corrosion Resistant Tempers

To increase the corrosion resistance of certain high-strength heat treatable alloys of the 7xxx series in particular, they are given an overaging or stabilization treatment following solution heat treatment and quenching, rather than being aged to peak strength as indicated by the T6 temper. Such treatments are designated by the use of the T7-type temper, and the digit following the T7 indicates something about the extent of the treatment and of the resultant level of corrosion resistance.

There are two basic variations of corrosion-resistance enhancement used for such alloys:

- *Enhanced stress-corrosion resistance, T73 temper:* Indicating aging sufficient to increase stress-corrosion resistance to a relatively high level, well above that of the T6-type temper but at approximately a 15% sacrifice in tensile yield strength.
- *Enhanced exfoliation corrosion resistance, T76 temper:* Indicating aging sufficient to improve resistance to exfoliation corrosion over that of the T6-type temper, but strengths about 5 to 10% less than those of the T6 temper. Note that this T76 temper has strengths superior to those available with the T73 temper, but it provides less resistance to SCC than the T73 temper.

The stress-corrosion enhancements may be used in combination with the special tempers for residual stress relief, as illustrated by the following examples:

- *T7651 plate:* Basic temper is T7, indicating solution heat treatment, quenching, and an artificial aging treatment beyond peak strength aimed at enhancing corrosion resistance in some manner. Degree of overaging is for enhanced exfoliation corrosion resistance: T76. Plate was subsequently stress relieved by stretching ½ to 3%: T7651.
- *T73510 extruded shape:* Basic temper is T7, indicating solution heat treatment, quenching, and an artificial aging treatment beyond peak strength aimed at enhancing corrosion resistance in some manner. Degree of overaging is for enhanced stress corrosion resistance: T73. Plate was subsequently stress relieved by stretching ½ to 3% without further straightening or twisting: T73510.

Temper Designation for Special or Premium Properties

There are times when applications with special needs, typically in the aerospace industry, require special performance capabilities of aluminum alloys. These capabilities are accomplished by the use of special processing (sometimes combined with tighter composition control). When special processing is used, and it is to be used in a fairly broad commercial manner, a special temper designation usually is developed. Several of these designations are noted subsequently.

Several years ago, special processes were developed to provide 7175 forging (7175 being a special version of 7075 with tighter impurity limits control) with a superior combination of high strength, high fracture toughness, and good corrosion resistance. The temper designation developed for 7175 forgings produced by this special processing was T736 (T73652 if stress relieved by compressive cold work). Broader use of this approach for 7175 as well as 7050 and potentially other high toughness, high corrosion-resistant alloys led to the redefinition and simplification of T736 to T74.

As is often the case with such special processing, the specific combinations of thermal and mechanical treatments used to achieve the properties required are not specifically spelled out in the literature, and in fact, individual producers may have their own proprietary processes to accomplish the needs. In such cases, the mechanical property limits for the special products are detailed so that the desired performance must be met; however, it is accomplished by individual producers. Examples of such products and special processes are as follows:

- *7175-T74 die forging:* Basic temper is T7, indicating solution heat treatment, quenching, and aging to achieve special properties (e.g., aging beyond peak strength). Special treatment used to enhance combination of strength, toughness, and corrosion resistance, with specification limits on fracture toughness as well as strength: T74
- *7175-T7454 die forging:* Basic temper is T7, indicating solution heat treatment, quenching, and aging to achieve special properties (e.g., aging beyond peak strength). Special treatment used to enhance combination of strength, toughness, and corrosion resistance, with specification limits on fracture toughness as well as strength: T74. Stress relieved by a combination of stretching and compressive cold work: T7454

Another means sometimes used to indicate special treatments by the temper designation is the use of an extra “6” added to T6 temper:

- *7175-T66:* Basic temper is T6, indicating solution heat treatment, quenching, and artificial aging. Special undefined treatment to achieve maximum strength: T66

The development of special temper designations to cover unique cases is under the auspices of the Product Standards Committee of the Aluminum Association, and proposals for such unique tempers arise with some regularity. It is always possible, therefore, that new temper designations are being developed and registered by the Aluminum

Association, and anyone interested in remaining abreast of such developments should purchase the Registration Records Series *Tempers for Aluminum and Aluminum Alloy Products* in addition to *Aluminum Standards and Data.*

It is strongly emphasized once again that it is incorrect and unethical for anyone—producer, heat treater, or customer/user—to make up a temper designation in a format that implies or might be misconstrued to mean that the alloy has been registered by the Aluminum Association and recognized by others in the industry. Such practices dilute the value and reliability of the entire temper designation standards recognized by the industry, the American National Standards Institute (ANSI), and the International Accord (see Chapter 8, "Selected References") community.

Tempers for Cast Aluminum Alloys

The temper designation system for cast aluminum alloys is basically the same as that for wrought aluminum alloys, but in practice, there are some significant differences in usage. The following discussion focuses on those differences while noting the similarities.

The descriptive sources for the aluminum alloy designation system, such as *Aluminum Standards and Data,* focus more strongly on wrought alloys than on the cast alloys, and this discussion, therefore, also includes guidance from the American Foundrymen's Society book, *Aluminum Casting Technology.*

Review of the Basic Tempers for Cast Alloys

For practical considerations, a review of the basic temper designations can be restricted to the three types of tempers in commercial usage for castings: F, O, and T, described as follows:

- *F, as fabricated:* This designation is used for cast products made by any casting process (e.g., sand casting, permanent mold casting, die casting, etc.) and refers to the condition of the casting as it comes from the molds without any further thermal or mechanical treatment. Unlike the case with wrought alloys, the F temper is a very common finish or final temper for castings, especially die castings. In addition, unlike wrought alloys, there are likely to be published typical mechanical properties and, in some cases, even minimum mechanical property limits published for the F temper. For example, 360.0-F designates a 360.0 casting as it has come straight from the mold and cooled to room temperature. In this alloy, this is likely to be the temper supplied to the purchaser.
- *O, annealed:* This designation is used for cast alloys that are annealed (i.e., given a high-temperature stabilization or recrystallization treat-

ment, sufficient to remove the effects of the thermal cycles it experienced during the casting and cooling processes, thermal treatments, and to result in a softening of the material and the minimum practical level of mechanical strength. For castings, the treatment may be used both to improve ductility and increase dimensional stability, but it is not a very common finish temper for castings as it is for wrought non-heat-treatable aluminum alloys. For example, 222.0-O designates a 222.0 casting whose most recent treatment has been holding at a high temperature (~415 °C, or ~775 °F) for 5 h, slow furnace cooling by a carefully defined program, intended for dimensional stability.

- *T, thermally treated to produce stable tempers other than O or F:* The T designation applies to any cast alloy that has been given a solution heat treatment followed by a suitable quench and either natural (i.e., in air) or artificial (i.e., in a furnace) aging. The T is always followed by one or more digits that define in general terms the subsequent treatments, which are discussed in more detail subsequently. For example: 356.0-T6 designates a 356.0 casting that has been heat treated, quenched, and artificially aged.

Subdivisions of the Basic Temper Types for Cast Alloys

For cast alloys, there are no standard variations and, therefore, no additional digits on the designations for the F and O tempers; the following discussion, therefore, focuses only on the T tempers.

For the T type of temper for aluminum castings, there are four commercially used subdivisions: T4, T5, T6, and T7. These subdivisions have generally the same meaning as for wrought alloys, but the usage varies slightly:

- T4 indicates the casting has been given a solution heat treatment and, without any cold work, naturally aged (i.e., at room temperature) to a stable condition. For most casting alloys this is an unstable temper, comparable to W for wrought alloys, and so most cast alloys are subsequently aged. Example: 295.0-T4
- T5 indicates the casting has been cooled from the casting process and then artificially aged (i.e., in a furnace). The artificial aging consists of holding at a sufficiently high temperature and sufficiently long time (e.g., 8 h at 175 °C, or 350 °F, or 24 h at 120 °C, or 250 °F) to permit precipitation hardening to take place. This process stabilizes the castings dimensionally, improves machinability, relieves residual stresses, and increases strengths somewhat. Example: 319.0-T5
- T6 indicates the casting has been solution heat treated and artificially aged to achieve maximum precipitation hardening. It results in relatively high strengths with adequate ductility and stabilizes properties and dimensions. Example: 295.0-T6

- T7 indicates the casting has been solution heat treated and artificially aged to an overaged (i.e., past peak strength) condition. This treatment is used to provide a better combination of high strength and high ductility and stabilization of properties and dimensions. Example: 356.0-T7

Additional digits are used sometimes with these T5, T6, and T7 tempers, but the variations are not as well defined for castings as for wrought products; they do denote variations from the standard practices of either casting or heat treating the part. For different alloys, the same temper designation may not always mean the same variation in casting or heat treating practice:

- *For T5:* The T51, T52, T53, T533, T551, and T571 tempers are recognized variations, intended to either increase dimensional stability or increase strength. For example, for 242.0-T571, the basic temper, T5, indicates that the casting has been cooled from the casting process and then artificially aged (i.e., in a furnace). A special chill was added as the casting cooled to ensure higher strengths.
- *For T6:* The T61, T62, and T65 variations exist and deal with variations in quench media and/or artificial aging conditions, once again to increase dimensional stability or improve certain properties. For example, for A356.0-T61, the basic temper, T6, indicates that the casting has been solution heat treated, quenched, and artificially aged following casting. The aging practice has been modified from the peak-strength treatment (which would have been indicated by T6) to ensure optimal performance.
- *For T7:* The T71, T75, and T77 tempers are recognized, also primarily to increase dimensional stability or improve certain properties. For example, for 355.0-T71, the basic temper, T7, indicates that the casting has been heat treated and artificially aged to an overaged (i.e., past peak strength) solution condition. The artificial aging practice has been modified to further enhance the corrosion resistance and ductility.

Unfortunately, there is no clear resource to document the exact nature and degree of consistency of these variations in temper for cast aluminum alloys, as only a few of the tempers for casting have been recently enough registered to appear in Aluminum Association publications such as the Registration Record Series *Tempers for Aluminum and Aluminum Alloy Products.* Many of the tempers go back many years and have not been through a rigorous rationalization process.

Importance to Understanding Aluminum Tempers

One of the main points of the preceding discussion is to demonstrate that what may seem like a complex or confusing set of coded numbers in a temper designation can actually be recognized and understood by looking at the individual letters and numbers and recognizing the function and meaning of each segment.

End users and their heat treaters and fabricators should understand these in considerable detail so that in their own subsequent processes they do not destroy some key capability provided by the producer's treatment. The heat treater, for example, is advised to constantly refer to specifications, drawings, and controlling documents, to ensure that the end customer's requirements are being followed explicitly. If this is not done, end-user fabricators or heat treaters may face the prospect of salvaging parts rejected by the customer.