International Temper Designation Systems for Wrought Aluminum Alloys:

Part I – Strain Hardenable (H Temper) Aluminum Alloys

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Introduction

As the need arose in the aluminum industry to describe standard temper treatments and establish uniform temper designations, The Aluminum Association has served as the main body registering aluminum alloys and temper designations in its ANSI H35.1 standard. This standard dates back to 1957 (American Standard H35.1-1957), when it consisted only of the designation system for wrought aluminum alloys that was originally developed by The Aluminum Association. The ANSI H35.1 standard was reissued in 1962 to add the temper designation system in effect in the U.S. since 1948. It has been revised many times over the years and since 1971 has been published by The Aluminum Association, Inc., the Secretariat for the Accredited Standards Committee (ASC) H35.

The Aluminum Association is the registrar under ANSI H35.1/H35.1(M) with regard to the designation and composition of wrought aluminum alloys and tempers registered in the U.S. and also the registrar under an international accord on the composition and designation of wrought aluminum alloys. The international alloy designations and chemical composition for wrought aluminum and wrought aluminum alloys are registered in the latest Teal Sheets 2009 published by The Aluminum Association in February 2009 as a revision to the April 2006 document; the publication of Teal Sheets 2009 is available as a free downloadable pdf from The Aluminum Association website: www.aluminum.org/tealsheets, as well as from the European Aluminium Association website: www.eaa.net/en/about-aluminium/standards/interntional-registration.

The latest document on ANSI alloy and temper designation systems for aluminum—ANSI H35.1/H35.1(M)-2009[1]—published by The Aluminum Assocation, Inc. is a revision of ANSI H35.1/H35.1(M)-2006. The edition combines the U.S. and metric versions of this publication, as the metric edition (ANSI H35.1M) has not been published as a separate document since 2004.

With regard to tempers of aluminum alloys, ANSI H35.1/H35.1(M)-2009 varies from the 2006 version in that new definitions were applied to assigned additional digits for T7 (overaged) temper variations as well as other clarifications of temper designations. The ANSI H35.1/H35.1(M)-2009 document also appears in its entirety in *Aluminum Standards and Data 2009*,[2] recently published by The Aluminum Association. As mentioned in *Aluminum Standards and Data 2009* and in the preface to the ANSI H35.1/H35.1(M)-2009 section on temper designations: "Since there is no international accord on designation and registration of tempers for wrought aluminum alloys and wrought aluminum alloy products, reference to ANSI H35.1/H35.1(M) may not always reflect actual properties and characteristics associated with the particular aluminum alloy temper."

This may be changing, slowly but surely. As late as 2003, there was no international accord for aluminum and aluminum alloy temper designations or temper registrations that served as product standards.[3] However, the global restructuring of the aluminum industry has made it imperative that aluminum alloy standards become more universal in order to assure consistency in the purchase and use of aluminum products worldwide. In this respect, the ANSI H35.1/H35.1(M) standard was the basis for ISO 2107, which is an attempt to unify the worldwide aluminum temper designation system. Yet differences in temper designations for wrought aluminum and aluminum alloys still exist from country to country. Even between the U.S. and European member countries of CEN (Comité Européen de Normalisation/European Committee for Standardization), where the EN 515 standard is very similar to the wrought alloy portion of ANSI H35.1 (M).[4] Some differences are noted in the respective temper designations and standards as late as 2008.[5]

Within the EAA (European Aluminium Association), the management of the EAA Standards Committee and all its interactions with European standardization activities relating to aluminum semi-products, castings, and alloys are now coordinated within the Gesamtverband der Aluminiumindustrie e.V./General Association of the Aluminum Industry (GDA), which took over responsibility for this field from EAA in 2008.[6] Teal Sheets 2009 is also available as a free download from the GDA website: www.aluinfo.de/index.php/technical-information.419.html. However, the Aluminum and Aluminum Alloys Technical Committee of the European Committee for Standardization (CEN/TC 132) is the group focusing on European standardization for aluminum products, including EN 515 for wrought alloy temper designations.

This article (Part I) attempts to summarize the latest information on temper designations and definitions established worldwide for wrought aluminum alloys under the general classification of strain-hardened (H temper). A subsequent article (Part II) will focus on thermally treated or heat treatable (T temper) wrought aluminum alloy tempers. Wrought aluminum alloys in the strain hardened (H temper) class are generally 1xxx, 3xxx, and 5xxx alloys, while those classified as thermally treated or heat treatable (T temper) are generally 2xxx, 6xxx, and 7xxx alloys. Finally, Part III will cover temper designations for casting alloys.

In this article, H temper designations in the ANSI H35.1/H35.1(M)-2009 standard will be reviewed with respect to changes from ANSI H35.1/H35.1(M)-2006, differences between the temper designations used in the U.S. under ANSI H35.1(M) and in Europe in CEN countries under EN 515 (Wrought Products/Temper Designations) will be noted, and some comparisons will be made with older temper designations used in various countries. For example, the older and now outdated DIN (Deutches Institut für Normung/German Industry Standard) and BS (British Standard) designations for aluminum tempers have been used in technical publications up to 1988 and perhaps later.[7] A comparison between the old and new systems is thus important if previously published knowledge on aluminum alloys is to be readable by those unfamiliar with the old system.

Basic Temper Designations of Wrought Aluminum Alloys

The ANSI H35.1/H35.1(M)-2009 temper designation system for all wrought aluminum alloys follows the alloy designation with the two separated by a hyphen. The basic temper designations in this system consist of the letters F, O, H, W, or T indicating the general process of product

manufacture or heat treatment (Table I). Subdivisions of the basic tempers are indicated by one or more digits that follow the letter, e.g., 1100-H14, 3003-O, 3004-H38, 5052-H32, 5083-H116, 5456-H321, etc. for strain hardenable aluminum alloys of the 1xxx, 3xxx, and 5xxx series, and 2024-T62, 6061-T451, 7075-T7351, etc. for heat treatable aluminum alloys of the 2xxx, 6xxx, and 7xxx series.

F	As fabricated and no mechanical properties specified (F stands alone)
O	Annealed to obtain lowest strength temper (O may be followed by a digit to indicate an annealed condition with special characteristics)
H	Strain-hardened wrought products with or without additional thermal treatment to reduce strength (H always is followed by two or more digits)
W	Solution heat-treated (W is an unstable temper due to natural aging at room temperature after solution heat-treatment)
T	Thermally heat-treated to produce stable tempers other than F, O, or H (T is always followed by one or more digits)

Table I. Basic temper designations per ANSI H35.1/H35.1(M)-2009 and adopted by the European EN 515 temper designation system.

Temper Designations Systems for Wrought Strain Hardenable Aluminum Alloys

Wrought aluminum alloys of the 1xxx, 3xxx, and 5xxx series are hardened by cold working, i.e., they are strain hardenable and not hardened to any significant degree by age hardening heat treatments. In sum total, Teal Sheets 2009 and its June 2009 addendum list 41 1xxx alloys, 48 3xxx alloys, and 96 5xxx alloys for a total of 185 internationally registered wrought strain hardenable aluminum alloys. As for all aluminum alloys, the temper designations for strain hardenable aluminum alloys are given after the alloy, e.g., 1100-H14, 3003-O, 3004-H38, 5052-H32, 5083-H116, 5456-H321, etc.

Temper designations for wrought strain hardenable aluminum alloys in the U.S. (ANSI H35.1/H35.1(M) standard) and CEN member countries of Europe (EN 515 standard) and the ISO 2107 standard follow essentially the same temper designation system (Table II), although the temper designations for wrought strain hardenable aluminum alloys in the former ISO and India systems may still differ (Table III). The ANSI H35.1/H35.1 (M), ISO 2107, and EN 515 standards utilize the temper designations of -F for as fabricated (no mechanical properties specified), -O for annealed, and -H for strain hardened. The old DIN (German Standards Institute) designations, used in the past in Germany and other European countries, are no longer valid. However, in correlating data from older literature, the old DIN temper designation can be easily compared with the recent designation as shown in Table III.

Full Annealing – O Temper

The O temper designation is applied to the fully annealed metallurgical condition that achieves complete recrystallization of the alloy, yielding the lowest strength, highest ductility, and the most workable characteristics. The O temper designation is used for all aluminum alloys, whether or not they are strain-hardenable or heat-treatable. Annealing practices (temperature, time, and heating and cooling rates) vary depending on the type of aluminum alloy and prior metallurgical condition. For the strain-hardenable aluminum alloys, the O temper designation stands alone.

As is typical of the effect of cold work on metals, the driving force for recrystallization in annealing is higher as the degree of cold work (strain-hardening) increases, thus resulting in a lower recrystallization temperature for annealing. Also, a high degree of cold work typically results in a finer recrystallized grain size upon annealing at recommended temperatures. Normally undesirable, coarse grains lead to a reduction in strength and ductility and can occur due to secondary recrystallization upon annealing of strain-hardened aluminum alloys at high temperatures (e.g., >1,000°F). Critical values of cold work of 2-15% in aluminum alloys can foster coarse grain growth during annealing at recommended temperatures that are well below 1,000°F. The recrystallization temperature is affected to varying degrees by the alloying elements; in aluminum alloys, alloying elements such as Mn, Cr, and Fe increase recrystallization temperature. In 5xxx alloys, for example, Mn levels above 0.6% increase recrystallization temperature to such an extent that recrystallization may be retarded during hot rolling, extrusion, or forging.

Temper	Description
F	As fabricated
O	Annealed to obtain lowest strength condition (products achieving the required annealed properties after hot forming processes may be designated as O temper)
H	Strain hardened
H1	Strain hardened only
H111	Annealed and cold worked by small amount during straightening or other processing so as not to qualify as annealed or O temper
H112	Slightly strain hardened from hot working or from limited cold work (mechanical property limits specified)
H116	Specially fabricated, controlled strain, corrosion resistant temper for Al-Mg alloys (mechanical property limits and intergranular and exfoliation corrosion resistance specified)
H11	Strain hardened, 1/8 hard
H12	Strain hardened, 1/4 hard
H14	Strain hardened, 1/2 hard
H16	Strain hardened, 3/4 hard
H18	Strain hardened, full hard (hardest commercially available)
H19	Strain hardened, extra hard temper for special applications
Hxx4	Patterned or embossed Hxx temper sheet
H2	Strain hardened more than desired amount and partially annealed
H2x	Strain hardened and partially annealed to 1/8, 1/4, 1/2, or full hard (x = 1, 2, 4, 6, 8 respectively)
H3	Strain hardened and stabilized to improve ductility
H3x	Strain hardened and stabilized to ¼, ½. ¾, or full hard (x = 2, 4, 6, 8 respectively)
H321	Specially fabricated, controlled strain, corrosion resistant temper for Al-Mg alloys (mechanical property limits and intergranular and exfoliation corrosion resistance specified)
H4	Strain hardened and lacquered or painted
H4x	Strain hardened and lacquered or painted with remaining strain hardening at ¼, ½. ¾, or full hard (x = 2, 4, 6, 8 respectively)

Table II. ANSI H35.1 temper designation system used presently in the U.S. and CEN member European countries, as well as ISO 2107, for strain hardened wrought aluminum and aluminum alloys.

Strain Hardened, Partially Annealed, Stabilized – H Tempers

In the strain hardened (H) tempers, the subsequent suffix digits indicate the particular treatments, described in Table II, used to achieve specified properties in given 1xxx, 3xxx, and 5xxx strain hardenable alloy products based on the respective product standards. The first suffix digit after H (Hx) indicates the type of treatment used to affect physical or mechanical properties in these alloys:

Temper per ANSI H35.1/H35.1(M) (see Table 2)	CEN Countries (EN 515)	ISO*	India (BIS)	Italy (UNI)	Norway (NS)	Sweden (SIS)	France* (NF)	UK* (BS)	DIN* 17007	DIN* 1712-2 1725-1	*WL
F	F	M,F	M	–	0	0	–	M	–	Fxx	.0
F, hot rolled	F	–	M	Hp	7	0	X400	M	.07	Fxx	.0
F, extruded	F	O	M	Hp	8	0	X300	M	.08	Fxx	.0
F, forged	F	O	M	Hp	8	0	X100/ X200	M	.08	Fxx	.0
Special cases	–	–	–	–	9	–	–				
F, strain hardened, hardness unspecified	F	M	–	Hp	10	0	–	–	.02	Fxx	(.8)
O	O	O	O	R	2	2	Xx10	O	.10	Wxx	.1
H1	H1	H1	H	H + % cw:	–	–	X**	H	–	Fxx	–
H111	H111	–	–	H20 = 20%	–	–	Xx16	–	–	Fxx	.2
H11	H11	H1A	–	cold work,	–	–	–	–	.22	Fxx	.2
H12	H12	H1B	H1	H40 = 40%	12	12	Xx01	H2	.24	Fxx	.2
H14	H14	H1D	H2	cold work,	14	14	Xx02	H4	.26	Fxx	.2
H16	H16	H1F	H3	etc.	16	16	Xx03	H6	.28	Fxx	.2
H18	H18	H1H	H4		18	18	Xx04	H8	.30	Fxx	.3
H19	H19	H1J	–	–	20 to 25	19	Xx05	–	.32 to .35	Fxx	.3
H2	H2	H2	–	H + %cw,	11	29	X**	–	–	–	.2
H21	H21	H2A	–	H20 = 20%	–	–	–	–	.23	Gxx	.2
H22	H22	H2B	H1	cold work	13	22	Xx01	H2	.25	Gxx	.2
H24	H24	H2D	H2	H40 = 40%	15	24	Xx02	H4	.27	Gxx	.2
H26	H26	H2F	H3	cold work,	17	26	Xx03	H6	.29	Gxx	.2
H28	H28	H2H	H4	etc.	19	28	Xx04	H8	.31	Gxx	.3
H3	H3	H3	–		–	–		–	–	–	–
H32	H32	H3B	H1		–	–		–	–	–	–
H34	H34	H3D	H2		–	–		–	–	–	–
H36	H36	H3F	H3		–	–		–	–	–	–
H38	H38	H3H	H4		–	–			–	–	–

*ISO – old designations – were replaced by ISO 2107, which is the latest revision of aluminum temper standards that conforms closely with EN 515 and ANSI H35.1/H35.1(M).

*France – outdated and obsolete, replaced by EN 515 temper designation system. "x" indicates type of semi-finished product: 1 = hand forging, 2 = drop forging, 3 = extruded profile, 4 = hot rolled sheet or strip, 5 = cold rolled sheet or strip, 6 = drawn products except wire, 7 = drawn wire.

*UK – outdated and obsolete, replaced by EN 515 temper designation system.

*DIN 17007 (Germany) – outdated and obsolete, replaced by EN 515 temper designation system.

*DIN 1712-2 and 1725-1 (Germany and German speaking countries) – outdated and obsolete, replaced by EN 515 temper designation system. Temper is indicated by a capital letter F, G, or W followed by numbers indicating minimum tensile strength to the nearest 10 N/mm^2 (1.45 ksi); e.g., for 5083, equivalent to the old German alloy designation AlMg4.5Mn (3.3547), in the hot rolled or annealed condition, F28 or W28 (alternatively F 28 or W 28) represented a tensile strength of 275 N/mm^2 (39.88 ksi) towithin 10 N/mm^2 (1.45 ksi) for either .07 (now F) or .10 (now O) tempers according to DIN 17007.

*WL (Germany) – outdated and obsolete, replaced by EN 515 temper designation system. WL temper designations were formerly based on the German aerospace Werkstoffblätter der Deutschen Luftfahrt.

Table III. Comparison of temper designations used in the U.S., CEN member European countries, and different or older standards for strain hardenable wrought aluminum alloys.[1,4-7]

1 – strain hardened by cold work only, 2 – cold worked more than desired amount and partially annealed, 3 – cold worked and stabilized, and 4 – cold worked and partially annealed due to lacquering or paint baking operations.

Cold working of these alloys is most often imparted by cold rolling, as sheet and plate are the most common 1xxx, 3xxx, and 5xxx alloy products available, although cold working can also be imparted by drawing, forging, or other metalworking process. As presented in Table II, the second suffix digit after H (H–_x) indicates the degree of residual hardening (H_1 – 1/8 hard to H_9 – extra hard) with tensile property specifications established for each set of digits. H1 (cold worked) tempers are preferred over H2 (cold worked more than the desired amount and partially annealed) tempers, because partial annealing requires precise temperature control to achieve the required mechanical properties, especially at high levels of cold work. H3 (strain hardened and stabilized) tempers for 5083 involve heating to soften and stabilize mechanical properties to improve forming.

Marine Markets – H116 and H321 Tempers

As part of the efforts by the aluminum industry to eliminate potential problems in the selection of aluminum alloys and tempers for the marine market, The Aluminum Association has modified the definitions of both the H116 and H321 tempers of 5xxx aluminum alloys with magnesium contents above 3%.[8] Product forms for 5xxx-H116 and 5xxx-H321 are almost exclusively sheet and plate. Prior to 2004, the H116 temper only required exfoliation corrosion resistance testing, and the H321 temper required no corrosion testing. Present requirements for 5xxx alloys with magnesium contents above 3%, approved by ASC H35 and published for the first time in ANSI H35.1/H35.1(M)-2004, maintained in ANSI H35.1/H35.1(M)-2009, and adopted in ASTM B 928/B 928-2007,[9] specify H116 and H321 for continuous service at temperatures no greater than 150°F in marine environments, and are as follows:[1]

•H116 – Applies to products manufactured from alloys in the 5xxx series, for which the magnesium content is

3% nominal or more. Products are strain hardened at the last operation to specified stable tensile property limits and meet specified levels of corrosion resistance in accelerated type corrosion tests. They are suitable for continuous service at temperature no greater than 150°F (66°C). Corrosion tests include intergranular and exfoliation.

•H321 – Applies to products from alloys in the 5xxx series, for which the magnesium content is 3% nominal or more. Products are thermally stabilized after the last operation to specified stable tensile property limits and meet specified levels of corrosion resistance in accelerated corrosion tests. Corrosion tests include intergranular and exfoliation.

The marine service alloys and tempers include 5059-H116, 5059-H321, 5083-H116, 5083-H321, 5086-H116, 5383-H116, 5456-H116, 5456-H321, 5086-H321, and 5383-H321, for which mechanical property limits are specified.[2,4] Additionally, the alloys in these tempers are required to be tested to pass ASTM G 66[10] (exfoliation corrosion susceptibility) and ASTM G 67[11] (intergranular corrosion susceptibility) tests as defined in ASTM B 928.[9]

Intergranular and Exfoliation Corrosion Tests for H116 and H321 Tempers

The resistance to intergranular corrosion of individual lots of 5xxx-H116 and/or –H321 products is determined by the ASTM G 67 test or nitric acid mass loss test (NAMLT) and microscopic examination to assure a microstructure that is predominantly free of a continuous grain boundary network of aluminum-magnesium precipitate, often termed beta-phase. The beta-phase is highly anodic relative to the 5xxx alloy matrix. In the conduct of the NAMLT, mass loss after immersion in a concentrated nitric acid solution (70-72 wt%) at 86°F for 24 hours should be no greater than 15 mg/in^2 for absolute pass acceptance, while samples with a mass loss of 15.5-25 mg/in^2 need to be metallographically examined and compared with acceptable reference photomicrographs to assure pass acceptance.

Exfoliation corrosion occurs in products with a structure consisting of elongated and oriented grains and is caused by corrosion along stratified distributions of an anodic phase, i.e., the beta-phase in 5xxx alloys with magnesium contents greater than 3%. In the conduct of the ASTM G 66 test or ammonium salt solution exfoliation test (ASSET), samples immersed for 24 hours in a solution containing ammonium chloride, nitrate, tartrate, and hydrogen peroxide at 150°F are subjected to visual inspection to determine exfoliation corrosion susceptibility according to a series of standard photographs.

It should be noted that heating 5xxx alloys with more than 3% magnesium content for extended periods of time at or above 150°F leads to an almost continuous intergranular precipitation of beta-phase, leading to a condition called sensitization, which makes the alloy susceptible to intergranular corrosion, exfoliation corrosion, and stress corrosion cracking. Although the special tempers (either H116 or H321) avoid grain boundary precipitation of beta-phase in the as-received condition, they do not preclude eventual sensitization if the product is held at temperatures at or above 150°F.

For non-marine applications and per ASTM B 209, the 5xxx-H32 temper is available, although the choice between 5xxx-H321 per ASTM B 928 and 5xxx-H32 can be made depending on the need for corrosion testing.

Solution Heat Treatment and Aging of Strain Hardenable Aluminum Alloys

The solubility of alloying and trace elements in 1xxx, 3xxx, and 5xxx alloy solid solutions decreases rapidly with decreasing temperature, which results in most cases in some degree of supersaturation of these elements at room temperature upon cooling after hot working or annealing. Although these alloys are strain hardenable but not age hardenable in the conventional sense, a slight amount of age hardening may occur in the supersaturated solution due to negligible precipitation of some age hardenable phases, depending on the composition of some trace elements such as Si and Cu. No special temper designations are used for such heat treatments.

Strain Hardening Tempers of Age Hardenable Aluminum Alloys

Special products made of age hardenable aluminum alloys, normally available in F, O, and T tempers, are also available to a limited extent in H tempers.[2] For example, extruded 6101 alloy products are available in the H111 temper (annealed and cold worked by a small amount during straightening or other processing so as not to qualify as annealed or O temper). Some 2xxx, 6xxx, and 7xxx alloys in rivet and cold heading wire and rod are available in H13, H15, and H23 tempers to achieve high formability but with higher strength relative to the O temper. The fin stock/cladding alloy 7072 is a special case of a 7xxx alloy that is not available in T tempers but only in the O and H tempers.

Editor's Note: For more information on aluminum standards and data, go to The Aluminum Association website: www.aluminum.org.

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