DETERMINATION OF PROPERTIES FOR AMS METALS SPECIFICATIONS

(Tensile, Compressive, Elongation, RA, & Fracture Toughness)

INTRODUCTION- The purpose of this guideline is to establish consistent methods for determining statistically valid mechanical properties for AMS Specifications that cover metallic materials. The statistical methods described in this guideline shall be used to determine the specification minimums (also called "S-basis[1]" values) for the mechanical properties required by the specification. These properties may include ultimate tensile strength, tensile yield strength, elongation, reduction of area, compressive yield strength, plane-strain fracture toughness, or other mechanical property characteristics selected by the committee with the authority to approve the specification. These properties are applicable to all thicknesses, heat treat conditions, and product forms available for purchase and described in the specification.

DATA SUBMISSION- The sponsor of a draft for a new AMS specification (or a revision to the minimum mechanical properties for an existing specification) shall provide data to confirm the new technical requirements for the material. This data shall include consideration of specified sizes, product forms, heat treatments, thermomechanical treatments, and other variables affecting mechanical properties.

Data shall be submitted in electronic format to the Battelle representative for the MMPDS Handbook (www.mmpds.org). Contact Jana Rubadue and Carinne Shannon (rubaduej@battelle.org, shannon@battelle.org). With the spreadsheet data, also provide a text file with specimen dimensions, gage length, and all other relevant information. Units of measure must be noted in each data file.

Table 1 shows the format and general information required for each material. Table 2 shows required information for individual test results. Columns may be added on the far right if additional information is needed. For larger data sets (approaching sample size of 100 or greater), please contact Ms. Rubadue or Ms. Shannon for a data template file. This template may also be used for smaller data sets.

When specifying grain direction for wrought products, use the conventions L for longitudinal, LT for long transverse, and ST for short transverse. Products that are expected to have significantly different properties in directions other than those stated above should also be tested and reported.

The "Product Form" column must be filled out. Examples for wrought products are sheet, plate, bar, and forging. Examples for cast products are sand casting, investment casting, and permanent mold casting.

Table 1. General Data Header

Alloy Trade Name	Temper / Heat Treatment	Product Form	Supplier	Reference Number (optional	Industry / Government Specification Number	Specimen Location

[1] S-basis value: Where at least 99 percent of the population of values is expected to equal or exceed the minimum value with a 95 percent confidence

Table 2. Specimen Data Format for Determination of S-Basis Values

Grain Direction	Thickness(in) or Area (in^2)	Lot No.	Heat No.	TYS (ksi)	TUS (ksi)	ELG 4D (%)	RA (%)

DATA REQUIREMENTS - To compute the S-basis values, a minimum of 30 tests comprised of specimens from 3 different heats, casts, or melts must be provided for each property and test orientation. The reason for a minimum of 30 observations is that the S-basis value is a function of the number of observations (n). The one-sided tolerance limit factor (K_{99}), as shown in Table 4, has a value of 3.064 for n equal to 30. Sample sizes less than 30 will have higher one-sided tolerance limit factors (K_{99}) and will generally produce lower S-basis values.

For wrought products, this minimum data set (30 observations) shall be submitted for each thickness range. For wrought products where the tensile and compressive properties can vary significantly with thickness, regression analysis may be used. Regression analysis methods are identified in the "Other Statistical Procedures" section of this document.

Uniformity of Sample Size across Thickness Range - It is recommended that test data for small sample sizes be uniformly distributed across the thickness range. True uniformity is not required. The method described in this section is based on the Ahrens-Pincus Index [Reference: Ahrens, H., and R. Pincus, "On Two Measures of Unbalancedness in a One-Way Model and their Relation to Efficiency," *Biometrical Journal* 23:227–235 (1981)], and described in the following steps.

1. Divide the overall thickness range into 3 equal-thickness bins: left, center, right
2. Denote the numbers of samples in each bin by N_L, N_C, N_R
3. Redistribute any samples falling on a boundary to either of the two adjoining bins, whichever results in the most equally spaced arrangement (and update N_L, N_C, and N_R)
4. Denote the total by $N = (N_L + N_C + N_R)$
5. Calculate the Ahrens-Pincus Index using equation below (eliminates divide-by-zero problem is Nc = 0):

$$\omega = \frac{(9N_C/N)}{1 + N_C\left(\frac{1}{N_L} + \frac{1}{N_R}\right)}$$

6. If $\omega \geq 0.85$ then the data may be considered balanced
7. If $\omega < 0.85$, compute:
   $N_{MIN} = \text{Min}(N_L,N_R)$ and $N_{MAX} = \text{Max}(N_L,N_R)$
8. If $N_C \leq N_{MIN}$ and $(N_{MAX} / N_{MIN}) \leq 1.5$

then the data may be considered balanced

9. If the data are not balanced, then additional samples should be added until balance is achieved

An S-Basis dataset will be considered to exhibit sufficient balance, if:

(A) The Ahrens-Pincus Index is greater than or equal to 0.85

(B) The Ahrens-Pincus Index is less than 0.85 and N_C contains the fewest samples and (N_L/N_R) is contained in (2/3, 3/2)

Additional combinations shown in Table 3 would be available for N = 30.

Table 3. Combinations meeting requirements with few Nc data for N = 30.

N_L	N_C	N_R
12 to 18	0	Remainder
12 to 17	1	Remainder
12 to 16	2	Remainder
11 to 16	3	Remainder
11 to 15	4	Remainder
10 to 15	5	Remainder

COMPUTATION OF MINIMUM VALUES (S-BASIS) - Strength properties shall be validated by analysis using the statistical procedure below. Although the establishment of a specification limit should be based upon the computation of an estimated S-basis value, engineering judgement may be used to lower the calculated S-basis value to provide a more conservative specification limit. If the data are not normally distributed, the 50% Censored Normal method described below may be used if the R^2 value is 90% or greater. (See MMPDS for greater explanation of this method.) For sample sizes ≥100, other statistical methods are used as described in Chapter 9 of the MMPDS Handbook.

<u>S-Basis Procedure</u> - This procedure assumes that the data are normally distributed and supports an estimated S-basis value. The specification tensile and compressive strength properties may be determined in the following manner from test data. An estimated S-basis value may be computed by assuming the distribution of the sample population to be normal and utilizing the following equation:

$$S_{est} = \bar{x} - k_{99}\, s\,,$$

where:

$\bar{x}$ = sample mean

s = standard deviation (based upon sample population)

k_{99} = one-sided tolerance tolerance-limit factor corresponding to a proportion at least 0.99 of a normal distribution and a confidence coefficient of 0.95 (see Table 4).

S_{est} = estimated S-basis value before rounding.

Censored Normal Procedure – This procedure should be used when a mechanical property value is to be computed directly, the number of available samples, n, is small ($30 \le n < 100$), and the Anderson-Darling test for Normality has been rejected. The same equation is used with the exception of using the k_{99cens} value instead of k_{99}, while using the same original total sample size, n, from Table 4. The analysis must result in an R^2 value of at least 90% for the results to be valid. The procedure is further described in Chapter 9 of MMPDS.

Round-off Procedure - The standard round-off methods as described in ASTM E29 shall be employed to arrive at whole number S-basis value.

Elongation and Reduction of Area - The S-basis values for elongation and reduction of area may be calculated using the S-basis equations above. If there is a high degree of scatter, the minimum reported observation may be used.

Plane-strain Fracture Toughness - The S-basis values for plane-strain fracture toughness K_{Ic} may be calculated using the S-basis equations above. If there is a high degree of scatter, the minimum reported observation may be used. Whenever fracture toughness data exhibit positive skewness, transformations of the data (i.e. square-root or logarithm) should be considered prior to application of the S-basis equation.

For aluminum alloys, plane strain fracture toughness specification minimums shall be determined using test values obtained in accordance with ASTM E399 and ASTM B645. Where valid K_{Ic} values can be consistently obtained, only these values shall be used in determining the specification minimum. For those test orientations and product gauge ranges where the validity requirements of ASTM E399 cannot be consistently met, K_Q values "usable for lot release" per ASTM B645 may be used in determining the specification minimums. In this case, a specific specimen size shall be given in the material specification and required to be used, and the specimen size shall be the same as that used to establish the minimum values of fracture toughness. A valid K_{Ic} meeting the requirements of ASTM E399, or a K_Q "usable for lot release" per ASTM B645 that meets or exceeds the minimum values in the material specification shall be evidence of meeting the plane strain fracture toughness requirement.

Other Statistical Procedures - The above statistical procedures are recommended for the substantiation of the minimum mechanical properties for sample sizes less than 100. However, the sponsor may elect to apply the statistical procedures in MMPDS to substantiate the minimum mechanical properties if all the requirements for sample size are met. The methods outlined in Chapter 9 of MMPDS for the computation of the T_{99} value are to be used (not the T_{90} methods) to establish the S-basis value for an AMS specification.

Chapter 9 of MMPDS also contains statistical methods to compute the minimum mechanical properties using regression analysis techniques. These procedures may be used to compute the minimum mechanical properties for an AMS specification if all the data requirements stated in MMPDS for these procedures are met. The methods for the computation of the T_{99} value are to be used (not the T_{90} methods) to establish the S-basis value for an AMS specification.

Table 4. One-Sided Tolerance Limit Factors, k, for the Normal Distribution, 95% Confidence, and n-1 Degrees of Freedom (from Table 9.10.1 of MMPDS)

Note: The k_{99} are to be used only for substantiation of S-basis minimum properties per Normal (S-basis) (MMPDS Section 9.4.1) or the k_{99cens} only for 50% Censored Normal analysis (MMPDS Section 9.5.5.4). Weibull, Pearson, or nonparametric procedures should be used when the sample size is 100 or more (see MMPDS Section 9.5).

n	Uncensored, 95% Confidence[a]		50% Censored, 95% Confidence[b]	
	k_{99}	k_{90}	k_{99cens}	k_{90cens}
30	3.064	1.777	3.989	2.396
31	3.048	1.767	3.949	2.370
32	3.034	1.758	3.913	2.347
33	3.020	1.749	3.878	2.324
34	3.007	1.740	3.845	2.300
35	2.995	1.732	3.815	2.281
36	2.983	1.725	3.785	2.262
37	2.972	1.717	3.757	2.242
38	2.961	1.710	3.730	2.224
39	2.951	1.704	3.705	2.209
40	2.941	1.697	3.680	2.191
41	2.932	1.691	3.657	2.176
42	2.923	1.685	3.635	2.161
43	2.914	1.680	3.613	2.148
44	2.906	1.674	3.593	2.134
45	2.898	1.669	3.574	2.121
46	2.890	1.664	3.555	2.109
47	2.883	1.659	3.537	2.097
48	2.876	1.654	3.520	2.085
49	2.869	1.650	3.503	2.074
50	2.862	1.646	3.487	2.065
51	2.856	1.641	3.472	2.054
52	2.850	1.637	3.457	2.044
53	2.844	1.633	3.443	2.034
54	2.838	1.630	3.429	2.026
55	2.833	1.626	3.416	2.016
56	2.827	1.622	3.403	2.008
57	2.822	1.619	3.391	2.000
58	2.817	1.615	3.379	1.992
59	2.812	1.612	3.367	1.984
60	2.807	1.609	3.355	1.976
61	2.802	1.606	3.344	1.969
62	2.798	1.603	3.334	1.962
63	2.793	1.600	3.323	1.955
64	2.789	1.597	3.313	1.948
65	2.785	1.594	3.304	1.942
66	2.781	1.591	3.294	1.935
67	2.777	1.589	3.285	1.930
68	2.773	1.586	3.276	1.924
69	2.769	1.584	3.267	1.918
70	2.765	1.581	3.259	1.912
71	2.762	1.579	3.250	1.907
72	2.758	1.576	3.242	1.900
73	2.755	1.574	3.235	1.896
74	2.751	1.572	3.226	1.891
75	2.748	1.570	3.220	1.886
76	2.745	1.568	3.212	1.881
77	2.742	1.565	3.205	1.875
78	2.739	1.563	3.198	1.871
79	2.736	1.561	3.192	1.866
80	2.733	1.559	3.185	1.862
81	2.730	1.557	3.179	1.858
82	2.727	1.556	3.172	1.854
83	2.724	1.554	3.165	1.850
84	2.721	1.552	3.159	1.846
85	2.719	1.550	3.154	1.842
86	2.716	1.548	3.148	1.838
87	2.714	1.547	3.143	1.835
88	2.711	1.545	3.137	1.831
89	2.709	1.543	3.132	1.826
90	2.706	1.542	3.126	1.824
91	2.704	1.540	3.121	1.820
92	2.701	1.538	3.115	1.816
93	2.699	1.537	3.110	1.814
94	2.697	1.535	3.106	1.809
95	2.695	1.534	3.101	1.807
96	2.692	1.532	3.096	1.803
97	2.690	1.531	3.091	1.800
98	2.688	1.530	3.087	1.798
99	2.686	1.528	3.082	1.794
100	2.684	1.527	3.078	1.792

a The following equations may be used to compute k factors in lieu of using table values:
These are accurate to within +/- 0.002 of the table values for n greater than or equal to 30.

$k_{99} = 2.326 + \exp[1.34-0.522 \ln(n)+3.87/n]$

$k_{90} = 1.282 + \exp[0.958-0.520 \ln(n) +3.19/n]$

b The following equations may be used to compute k_{cens} factors in lieu of using table values:

$k_{99cens} = k_{99} \times [1.0675 + 8.3128/n - 38.4384/n^2]$

$k_{90cens} = k_{90} \times [1.0830 + 9.4726/n - 45.2377/n^2]$