DETERMINATION OF
PROPERTIES FOR AMS METALS SPECIFICATIONS
(Tensile, Compressive, Elongation, RA, & Fracture Toughness)

INTRODUCTION - This guideline has been established to provide a consistent method that ensures the validity of mechanical property requirements for AMS specifications covering metallic materials. The statistical methods described shall be used to determine the specified limits (also called "S-basis") for mechanical properties required by the specification such as ultimate tensile strength, tensile yield strength, elongation, reduction of area, compressive yield strength, or other mechanical property characteristics selected by the committee with jurisdiction for the specification. These properties are applicable to the metallurgical form (thickness and heat treat condition) in which the product is purchased and to any related metallurgical form (other condition resulting from response to heat treat) that is also a requirement of the specification (i.e., -T351 and -T851, respectively).

DATA SUBMISSION - The sponsor of a new AMS specification or a revision involving changes to the minimum mechanical properties shall provide with the draft the data to substantiate the new or changed 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) rubaduej@battelle.org. Along with the spreadsheet data, provide a text file containing other relevant supporting documentation such as specimen dimensions, gage length, etc. The data's units of measure shall be noted in each data file.

Tables 1A and 1B, for wrought and cast products respectively, show the type of information to be supplied and the format. The columns (or data fields), in order, will contain alloy type, specification number, temper/heat treatment, lot and/or heat number, product form, product thickness, specimen location, grain direction (for wrought product), and specimen number. Columns will be added towards the right of the specimen number in Tables 1A and 1B as shown in Table 2. Table 2 will contain the individual test results when assembled with Tables 1A or 1B. For larger data sets (approaching sample size of 100 or greater), please contact Ms. Rubadue 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 anticipated to have significantly different properties in directions other than those stated above should be tested in the appropriate directions and the results reported.

There are several types of product forms covered by AMS; therefore, the term product form should be properly defined and reported in this column. Examples for wrought products are sheet, plate, bar, and forging. Examples for cast products are sand casting, investment casting, and permanent mold casting.

DATA REQUIREMENTS - To compute the S-basis values, it is required that a minimum of 30 observations be provided representing 3 heats, cast, or melts of material. The reason 30 observations are required is due to the fact that the computation of the S-basis value is a function of the number of observations (n). The one-sided tolerance limit factor ( ), as shown in Table 3, has a value of 3.064 for n equal to 30. Sample sizes less than 30 will have higher one-sided tolerance limit factors ( ) and will generally produce lower S-basis values.

For wrought products, this minimum data set (30 observations) shall be submitted for each thickness range. Another approach for wrought products where the tensile and compressive properties can vary significantly with thickness is to use regression analysis. Regression analysis methods are identified in the subsection on Other Statistical Procedures.

It is also recognized that for new specifications covering recently developed materials, only limited quantities of data may be available. When only very small quantities of data are available, particularly for compressive yield strength, properties may be derived by determining the relationship to an established tensile property. This indirect method of computation using paired ratios is applicable to tensile ultimate and tensile yield strengths in grain directions other than the specified testing direction, and for all grain directions for secondary properties (such as compressive). Paired ratio analysis methods are identified in the subsection on Other Statistical Procedures.

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:
   $N_{MIN} = Min(N_L,N_R)$ and $N_{MAX} = Max(N_L,N_R)$
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 1 would be available for N = 30.

Table 1 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) - For tensile and compressive strength properties, the substantiation shall be based upon the analysis of the data using the statistical procedure below. Although the establishment of a specification limit (S-basis*) should be based upon the computation of an estimated S-basis value, the specification value may vary slightly with the estimated S-basis value based upon experience and judgment. For sample sizes ≥100, other statistical methods are preferred as described in Chapter 9 of the MMPDS Handbook.

Ultimate, Yield, and Compressive Strength - 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:

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

where:

$\overline{x}$ = 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 3).

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

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 equation above or, when 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 equation above or, when 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, for example, square-root or logarithm, should be considered prior to application of the S-basis equation. When there are sufficient data, other statistical procedures as described below may be used.

* At least 99 percent of the population of values is expected to equal or exceed the S-basis mechanical property value, with a confidence of 95 percent.

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 procedure is recommended for the substantiation of the minimum mechanical properties; however, the sponsor may elect to apply the statistical procedures in MMPDS to substantiate the minimum mechanical properties provided all the requirements for sample size are met. The methods outlined in Chapter 9 of MMPDS for the computation of the T99 value are to be used (not the T90 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 and paired ratios analysis techniques. These procedures may be used to compute the minimum mechanical properties for an AMS specification provided all the data requirements stated in MMPDS for these procedures are met. The methods for the computation of the T99 value are to be used (not the T90 methods) to establish the S-basis value for an AMS specification.

Table 1A – General Data Format for Wrought Products

Alloy Trade Name	Industry or Government Specification Number	Temper or Heat Treatment	Heat or Melt Number	Lot Number	Product Form	Product Thickness (in), or Area (in^2)	Specimen Location	Grain Direction	Specimen Number

Table 1B – General Data Format for Cast Products

Alloy Trade Name	Industry or Government Specification Number	Temper or Heat Treatment	Heat or Melt Number	Lot Number	Product Form	Product Thickness (in), or Area (in^2)	Specimen Location	Specimen Number

Table 2 – Data Format for Determination of S-Basis Values

Alloy Trade Name			Specimen Number	TUS (KSI)	TYS (ksi)	Percent E	Percent R	Elastic Modulus (ksi)

Table 3 – One sided tolerance limit factors, k_{99}, corresponding to at least a 99% proportion of a normal distribution with a confidence of 95% and n-1 degrees of freedom.

n	k_{99}	n	k_{99}	n	k_{99}	n	k_{99}	n	k_{99}	n	k_{99}
		46	2.890	91	2.704	136	2.627	181		330	
2	37.094	47	2.883	92	2.701	137	2.626	182		335	
3	10.553	48	2.876	93	2.699	138	2.625	183		340	
4	7.042	49	2.869	94	2.697	139	2.624	184		345	
5	5.741	50	2.862	95	2.695	140	2.622	185		350	
6	5.062	51	2.856	96	2.692	141	2.621	186		355	
7	4.642	52	2.850	97	2.690	142	2.620	187		360	
8	4.354	53	2.844	98	2.688	143	2.619	188		365	
9	4.143	54	2.838	99	2.686	144	2.618	189		370	
10	3.981	55	2.833	100	2.684	145	2.617	190		375	
11	3.852	56	2.827	101	2.682	146	2.616	191		380	
12	3.747	57	2.822	102	2.68	147	2.614	192		385	
13	3.659	58	2.817	103	2.678	148	2.613	193		390	
14	3.585	59	2.812	104	2.676	149	2.612	194		395	
15	3.520	60	2.807	105	2.674	150	2.611	195		400	
16	3.646	61	2.802	106	2.672	151	2.610	196		425	
17	3.414	62	2.798	107	2.671	152	2.609	197		450	
18	3.370	63	2.793	108	2.669	153	2.608	198		475	
19	3.331	64	2.789	109	2.667	154	2.607	199		500	
20	3.295	65	2.785	110	2.665	155	2.606	200		525	
21	3.263	66	2.781	111	2.663	156	2.605	205		550	
22	3.233	67	2.777	112	2.662	157	2.604	210		575	
23	3.206	68	2.773	113	2.66	158	2.603	215		600	
24	3.181	69	2.769	114	2.658	159	2.602	220		625	
25	3.158	70	2.765	115	2.657	160	2.601	225		650	
26	3.136	71	2.762	116	2.655	161	2.600	230		675	
27	3.116	72	2.758	117	2.654	162	2.600	235		700	
28	3.098	73	2.755	118	2.652	163	2.599	240		725	
29	3.08	74	2.751	119	2.651	164	2.598	245		750	
30	3.064	75	2.748	120	2.649	165	2.597	250		775	
31	3.048	76	2.745	121	2.648	166	2.596	255		800	

n	k_{99}	n	k_{99}	n	k_{99}	n	k_{99}	n	k_{99}	n	k_{99}
32	3.034	77	2.742	122	2.646	167	2.595	260		825	
33	3.020	78	2.739	123	2.645	168	2.594	265		850	
34	3.007	79	2.736	124	2.643	169	2.593	270		875	
35	2.995	80	2.733	125	2.642	170	2.592	275		900	
36	2.983	81	2.73	126	2.640	171	2.592	280		925	
37	2.972	82	2.727	127	2.639	172	2.591	285		950	
38	2.961	83	2.724	128	2.638	173	2.59	290		975	
39	2.951	84	2.721	129	2.636	174	2.589	295		1000	
40	2.941	85	2.719	130	2.635	175	2.588	300		1500	
41	2.932	86	2.716	131	2.634	176	2.587	305		2000	
42	2.923	87	2.714	132	2.632	177	2.587	310		3000	
43	2.914	88	2.711	133	2.631	178	2.586	315		5000	
44	2.906	89	2.709	134	2.630	179	2.585	320		10000	
45	2.898	90	2.706	135	2.628	180	2.584	325			