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RESEARCH REPORT

DETERMINATION OF DESIGN ALLOWABLE STRENGTH PROPERTIES OF ELEVATED-TEMPERATURE ALLOYS
PART 1 — COATED COLUMBIUM ALLOYS

to

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Battelle
Columbus Laboratories

FINAL REPORT

on

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by

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DETERMINATION OF DESIGN ALLOWABLE STRENGTH PROPERTIES OF ELEVATED-TEMPERATURE ALLOYS

PART 1 — COATED COLUMBIUM ALLOYS

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INTRODUCTION

The selection of candidate materials for an aerospace vehicle, such as the NASA space shuttle, is initially made on the strength of available material properties and design criteria which describe environmental characteristics, vehicle requirements, etc. As candidates are eliminated during the preliminary design processes, for a variety of reasons, a manageable list of likely materials becomes evident. Attention first is focused on developing tentative and then firm design allowables for these materials.

A broad range of alloys are being considered for the booster and orbiter vehicles. For this program, NASA considered it desirable to focus on a small number of materials capable of use at moderate-to-high elevated temperatures (up to 2400 F). The materials selected consisted of three nickel-base alloys (Hastelloy X, René 41, and Inconel 718), one cobalt-base alloy (L-605), and two coated columbium-alloy systems. The specific interest was in properties of thin-sheet materials, especially in the thickness range 0.010 to 0.030 inch.

The overall report of the results of this program is in two parts; Part 1 on Coated Columbium Alloys and Part 2 on Superalloys, each consisting of a separate report. This report is concerned with Part 1 of the program (although the objectives of the total program are given in the following section). The final section contains only conclusions arrived at from the detailed study of the coated-columbium program results.

OBJECTIVES

The specific objectives of this program were as follows:

(1) Selection and experimental evaluation of the tensile properties of two coated columbium-alloy systems with a nominal 3-mil coating to determine design allowables

information for use in selected applications in the space shuttle vehicles.

(2) Determination of the effect of cyclic exposure of the nature of that expected for the space shuttle vehicles on the mechanical properties of the two coated columbium-alloy systems. The cycle life evaluated was for 5, 10, and 30 exposures.

(3) Determination of the behavior of butt-welded joints in the two coated columbium-alloy systems.

(4) Collection and evaluation of existing design-property data on Hastelloy X, René 41, and Inconel 718 nickel-base alloys; and L-605 cobalt-base alloy.

The coated columbium-alloy systems ultimately selected were R512E/Cb752 and VH109/C129Y. The temperature range for the studies was from room temperature (RT) to 2400 F.

SUMMARY

In developing design allowables information on two coated columbium-alloy systems, a comprehensive program was conducted on as-coated base material, as-coated butt-welded material, and as-coated material thermal/pressure (T/P) cycled prior to testing up to 30 cycles. Evaluation was by means of tensile tests covering the temperature range RT to 2400 F. From the data obtained and subsequent analysis, design allowables have been computed and presented in the Design Allowables Summary section of this report. This summary includes a room-temperature property table, effect-of-temperature curves, and typical stress-strain curves. It is believed that the present design allowables information should be considered as tentative, pending the addition of other data resulting from other NASA programs presently under way. With regard to butt-weld behavior, weld efficiencies are presented for both coating/alloy systems that are considered applicable over the temperature range tested. Similarly, reduction factors are presented to account for the slight strength decreases observed after T/P exposures.

With the exception of samples of R512E/Cb752 cycled for 30 T/P cycles, both coating/alloy systems showed high reliability after T/P cycling. In the case of the R512E/Cb752 samples cited above, coating wear-out failure probably occurred because the partial pressure of O_2 in the simulating environment was lower than intended.

Extensive coating thickness measurements during the program provided a statistical estimate of coating thickness variability for the two systems. The results show that the VH109/C129Y system had somewhat greater variability than did the R512E/Cb752 system, which was reflected in some of the data by greater variability in properties. This variability is believed to be associated with process control, which probably can be improved with further development.

Property-wise, the VH109/C129Y system showed higher strength than did the R512E/Cb752 system. In part, this reflects the higher strength of the base metal and the somewhat thinner (on the average) VH109 coating when compared with the average coating thickness obtained with R512E.

While concentration in this program has been on tensile properties, future studies of coated columbium alloy should be concerned with compression properties, fatigue, and creep/fatigue interaction.

RESEARCH PLAN

One of the most difficult problems in developing design allowables information on coated colbumium alloys is the assembly of information on a reasonably compatible grouping of products. Generally, one tries to obtain sets of data on similarly processed base material, as well as material coated in a standard manner with a standard process. The nature of coated columbium-alloy technology during the past several years can be characterized as one of research and development, both in regard to the base material and its processing, and to the coatings and their application. Thus, it was decided early in the program to consider available data only as indicative and to conduct analyses on only those data generated on this program. Several other programs subsequently are identified that will provide additional data to the present data base from this program and permit a more rigorous statistical analysis of design allowables.

In order to develop design data in reasonable quantity for statistical analysis, the approach in this program was to (1) identify from past research significant variables affecting the properties of coated columbium, (2) select material/condition/coating combinations from this information, (3) acquire and process the alloy/coating systems, (4) evaluate the material in the base alloy/coating combination and in the welded/coated condition, and (5) determine the effects of a cyclic temperature/pressure environment on the mechanical properties of the alloy/coating systems. The following sections describe the details of these steps.

LITERATURE SURVEY

This program was initiated with a survey of past and current information for mechanical property data on selected coated columbium alloys. As agreed with the NASA Technical Monitor, this search was restricted to data for alloy sheet of the Cb752 (Cb-10W-2.5Zr), C129Y (Cb-10W-10Hf-0.1Y), and FS85 (Cb-28Ta-11W-1Zr) alloys in gages from 0.010 through 0.060 inch thick. A further qualification regarding these alloys was that property data were only of interest for each alloy in the single-annealed, fully recrystallized condition. The coatings of interest were restricted to the R512E (Si-20Cr-20Fe) slurry-silicide coating developed by Sylvania Electric Products, Hicksville, New York; and two proprietary slurry-silicides coatings (VH101 and VH109) developed by the Vac-Hyd Processing Corporation, Torrance, California.

The survey consisted of a thorough search of the Metals and Ceramics Information Center at Battelle's Columbus Laboratories (BCL) and contacts with representatives of the following organizations:

- The Boeing Company, Seattle, Washington
- General Dynamics, Convair Division, San Diego, California
- General Electric Company, Space Technology Center, Valley Forge, Pennsylvania
- The Marquardt Corporation, Van Nuys, California
- McDonnell Douglas Corporation, Astronautics Division, St. Louis, Missouri
- North American Rockwell Corporation, Space Division, Downey, California
- Sylvania Electric Products, Hicksville, New York
- Vac-Hyd Processing Corporation, Torrance, California
- Wah Chang Albany, Albany, Oregon.

In the series of discussions, it was determined that several of the above aerospace organizations were in the process of generating mechanical property data on R512E/Cb752 and VH109/Cb752 systems. These programs represented in-house efforts. It also was determined that a part of a NASA-Langley Research Center program at General Dynamics/Convair and a NASA-Lewis Research Center program at McDonnell Douglas Corporation will provide some information that might be added to a design allowables data bank on R512E/Cb752, R512E/C129Y, and R512E/FS85 systems. It is expected that, when these data are complete, they can be combined with the results of this program.

Only a modest amount of property data were uncovered from the literature for the R512E/Cb752 system, and only a few scattered data points were obtained for the other systems of interest. The tensile properties from the literature are summarized in Table 1, where it is noted that most of the data are for the R512E/Cb752 system. A variety of environments, including vacuum, helium, and air at several pressures were included in the tests that ranged from RT to 2600 F. Three substrate thicknesses were tested in the range 0.012 inch to 0.032 inch. Much of these data involve single test results. With the large scatter noted in the results, it is difficult to establish definite conclusions on the effect of the variables tested on strength properties.

Table 2 provides creep-stress versus time to obtain 2 percent creep at 2400 and 2600 F for R512E/Cb752, whereas Figure 1 shows a comparison of stress-time to obtain 2-percent creep curves and data for coated and uncoated Cb752 at the same temperatures. Considerable scatter are seen at 2600 F; however, there appears to be little difference in creep behavior for uncoated and coated Cb752, as shown by these limited data.[6]

TABLE 1. SUMMARY OF AVAILABLE TENSILE PROPERTY DATA FOR COATED COLUMBIUM-ALLOY SYSTEMS OF INTEREST

Test Temperature, F	Number of Specimens Tested	Test Environment		Properties Evaluated			Substrate Thickness, inch	Reference[a]
		Gas	Pressure, torr	F_{tu}	F_{ty}	Elongation		
				R512E/Cb752 System				
RT	3	Vacuum	$< 10^{-4}$	82.7[b]	60.2[b]	19	0.016	(1)
1300	3	Vacuum	$< 10^{-4}$	60.4[b]	37.7[b]	10	0.016	(1)
1800	3	Vacuum	$< 10^{-4}$	49.7[b]	36.5[b]	13	0.016	(1)
2400	3	Helium	700	25.3[b]	23.7[b]	58	0.016	(1)
2600	3	Helium	700	12.1[b]	11.6[b]	104	0.016	(1)
RT	2	Air	760	80.3	58.4	22	0.030	(2)
1100	1	Air	760	42[c]	--	7[d]	0.012	(3)
1500	1	Air	760	45[c]	--	5[d]	0.012	(3)
1850	1	Air	760	42[c]	--	1[d]	0.012	(3)
2250	1	Air	760	42[c]	--	1[d]	0.012	(3)
1100	1	Air	1	56[c]	--	2.9[d]	0.012	(3)
1500	1	Air	1	58[c]	--	3.1[d]	0.012	(3)
1850	1	Air	1	55[c]	--	3.5[d]	0.012	(3)
2250	1	Air	1	48[c]	--	4.3[d]	0.012	(3)
1100	1	Air	10^{-1}	52[c]	--	2.3[d]	0.012	(3)
1500	1	Air	10^{-1}	56[c]	--	3.0[d]	0.012	(3)
1850	1	Air	10^{-1}	58[c]	--	5.0[d]	0.012	(3)
2250	1	Air	10^{-1}	48[c]	--	5.9[d]	0.012	(3)
RT	1	Air	10^{-2}	81[c]	--	12[d]	0.012	(3)
1100	1	Air	10^{-2}	56[c]	--	4.3[d]	0.012	(3)
1500	1	Air	10^{-2}	61[c]	--	3.8[d]	0.012	(3)
1850	1	Air	10^{-2}	56[c]	--	4.8[d]	0.012	(3)
2250	1	Air	10^{-2}	50[c]	--	3.2[d]	0.012	(3)
RT	1	Air	10^{-4}	77[c]	--	10.4[d]	0.012	(3)
1100	1	Air	10^{-4}	52[c]	--	5.6[d]	0.012	(3)
1500	1	Air	10^{-4}	43[c]	--	2.6[d]	0.012	(3)
1850	1	Air	10^{-4}	50[c]	--	4.3[d]	0.012	(3)
2250	1	Air	10^{-4}	35[c]	--	5.2[d]	0.012	(3)
1100	1	Air	760	47[c]	--	10[d]	0.032	(3)
1500	1	Air	760	38[c]	--	5[d]	0.032	(3)
1850	1	Air	760	38[c]	--	2[d]	0.032	(3)
2250	1	Air	760	35[c]	--	9[d]	0.032	(3)
RT	1	Air	10^{-4}	79[c]	--	17.4[d]	0.032	(3)
1100	1	Air	10^{-4}	52[c]	--	7.4[d]	0.032	(3)
1500	1	Air	10^{-4}	51[c]	--	9.6[d]	0.032	(3)
1850	1	Air	10^{-4}	44[c]	--	10[d]	0.032	(3)
2250	1	Air	10^{-4}	30[c]	--	4.8[d]	0.032	(3)
				VH109/C129Y System				
2000	1	Vacuum	--	41.5	31.2	10	0.014	(4)
				R512E/FS85 System				
2200	2	Air	760	32.5	24.6	8.7	0.045	(5)
RT	2	Air	760	83.8	63.4	22	0.030	(2)

(a) References are listed on page 93.

(b) Strengths are based on unreacted substrate.

(c) Strengths are based on original uncoated cross section.

(d) Percent elongation in 1-inch gage length.

TABLE 2. CREEP SUMMARY FOR R512E/Cb752 IN HELIUM AT 700 TORR (0.016-INCH SUBSTRATE THICKNESS)[a]

Test Temperature, F	Stress,[b] ksi	Time to 2% Creep, hr
2400	2.0	28.7
2400	3.0	16.0
2400	3.5	11.5
2400	4.0	9.8
2400	5.0	6.3
2400	6.0	4.2
2400	7.0	3.1
2400	8.0	2.4
2400	9.0	2.2
2600	1.0	9.0
2600	1.5	7.3
2600	2.0	4.5
2600	2.0	4.4
2600	2.5	3.5
2600	3.0	2.4
2600	4.0	1.7
2600	5.0	1.4
2600	6.0	0.3

(a) Data from Reference 6.
(b) Stress based on uncoated substrate area.

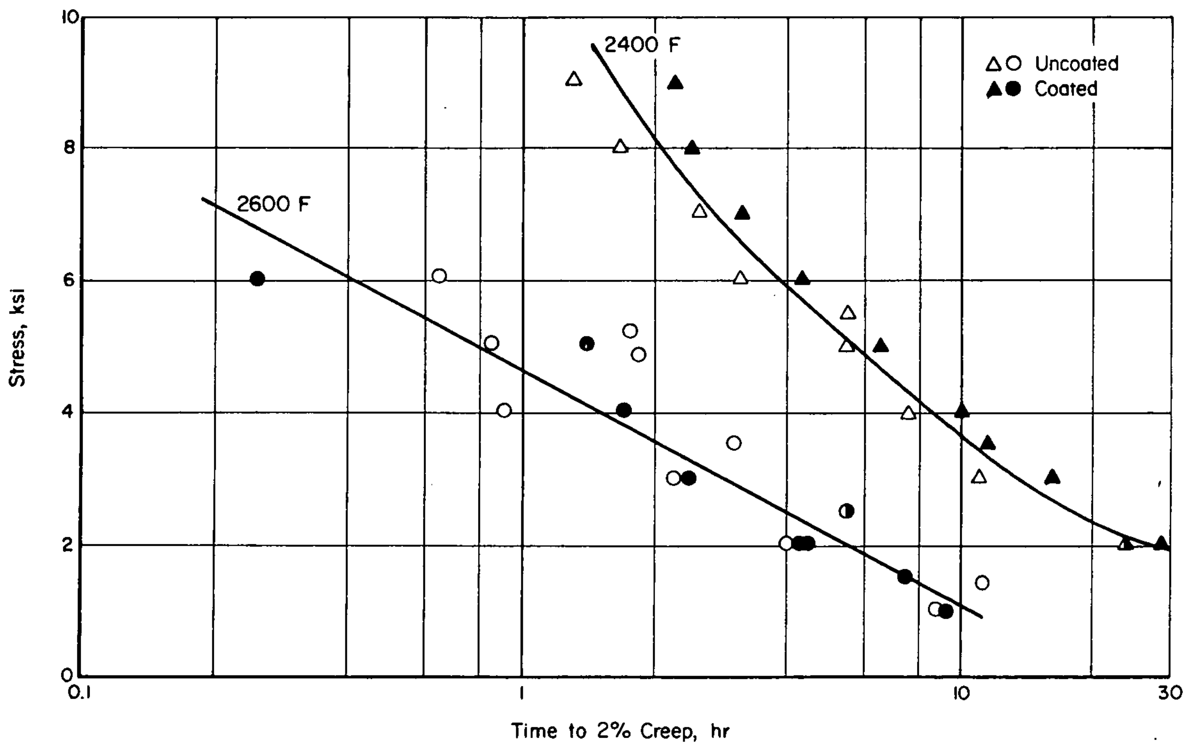

FIGURE 1. COMPARISON OF CREEP DATA FOR UNCOATED AND COATED Cb752[6]

Stress Based on Uncoated Substrate Area

Table 3 shows the results of a few stress-rupture tests on C129Y with VH109 and R512E coatings.[7]

TABLE 3. AVAILABLE STRESS-RUPTURE DATA FOR ALLOYS OF INTEREST

Test Temperature, F	Gas	Pressure, torr	Stress, ksi	Time to Rupture, hr	Substrate Thickness, inch	Reference
			VH109/C129Y			
2000	Vacuum	---	20[a]	9.2	0.014	(4)
2200	Vacuum	---	18[a]	6.7	0.014	(4)
2200	Vacuum	---	10[a]	123.9	0.014	(4)
2400	Vacuum	---	6[a]	100.5[b]	0.014	(4)
			R512E/C129Y			
2200	Air	760	10[c]	38.5	0.050	(7)
2200	Air	760	10[c]	34.4	0.050	(7)

(a) Stress based on coated dimensions.
(b) Did not rupture.
(c) Stress based on original uncoated specimen dimensions.

Obviously, these data collections are too meager to develop design allowables for any of the coating systems of initial interest to this program.

At the outset of the program, the R512E/Cb752 system was believed to represent the primary coated columbium system of interest to the space shuttle on the basis of available property and manufacturing information. The intense interest in this system, as evidenced by the aerospace company personnel, substantiated this belief.

The discussions also pointed toward one of the Vac-Hyd slurry-silicide coatings for use on the C129Y alloy. The choice appeared to be between either VH101 or VH109, without comparable data always available for making a decision. The following experiences were considered based on the indicated discussions.

(1) General Dynamics/Convair reported that good oxidation resistance was conferred to a VH109/C129Y heat shield and support structure in simulated reentry tests.[8,9]

Specifically, a 16-inch-square sheet metal test panel of this system successfully withstood 73 low-pressure (about 1 to 50 torr) simulated reentry profiling cycles involving accumulated exposures of 26.6 hours above 2000 F (to a peak temperature of 2470 F) without visual evidence of coating failure.

(2) At General Electric, 2000 F exposures in air and a "hard" vacuum indicated that equivalent oxidation resistance was accorded to VH109/C129Y and VH101/C129Y specimens, with the VH109/C129Y system being favored because of higher emissivity and greater thermal stability; i.e., a lesser degree of interdiffusion between the substrate and coating elements.(10) Other 2000 F comparative tests indicated that the VH109/C129Y system showed superior oxidation resistance and emissivity characteristics to the R512E/C129Y system.

(3) Wah Chang(4) and North American Rockwell(11) apparently favored VH109 over VH101 as a coating for the C129Y alloy, although their rationale for this selection was not made known.

(4) At Boeing, the cyclic (10-minute cycles) 2500 F oxidation behavior of the VH101 and VH109 coatings were compared on the C103 alloy (Cb-10Hf-1Ti-0.7Zr) in a chamber passing 200 SCFH air (at 70 F) across test specimens (chamber pressure of 1100 microns).(12) On this alloy substrate, the emittance of the VH101 coating was found to be much superior to the VH109 coating.

These interviews revealed that simulated reentry profiling experience with both coatings has been quite limited. The General Dynamics/Convair experience suggests VH109/C129Y to have good oxidation resistance, and the General Electric work with both VH101 and VH109 on the C129Y substrate favors the VH109 coating with regard to emissivity and thermal stability. These positive attributes (with the interest expressed by Wah Chang, North American Rockwell's Space Division, and McDonnell Douglas for VH109/C129Y) led to a recommendation for that system, with which NASA's Project Monitor concurred.

SPECIFYING AND PROCURING MATERIALS

The procurement specification for both Cb752 and C129Y was prepared and is listed in Appendix A.

An order was placed with Wah Chang, Albany, for the following quantities of 0.015-inch-thick columbium alloy sheet:

Alloy	Quantity Order, pound: Heat A	Heat B	Total A + B
Cb752	11.0	2.64	13.64
C129Y	11.5	2.68	14.18

The initial shipment, Heat A, consisted of five sheets of varying size of Cb752 and three sheets of C129Y. The second shipment, Heat B, consisted of one sheet of each alloy. The following tabulation lists specific heat numbers and sheet dimensions.

Alloy	Heat No.	Sheet No.	Approximate Dimensions, inches
	Heat A		
Cb752	770022	1	7-1/2 x 30
	770022	2	7-1/2 x 30
	770022	3	9 x 34
	770022	6	10 x 34
	770022	7	11 x 48
	Heat B		
	760055	1	13 x 38-3/4
	Heat A		
C129Y	572038	2	14 x 50
	572038	3	12-1/2 x 51
	572038	4	14 x 36
	Heat B		
	57006	1	7-3/4 x 43-3/8

Visual inspection showed each of the sheets to be free of oxide, cracks, seams, and other visible defects. The certification data are partially summarized in Tables 4 and 5 for Heats A and B, respectively. Examination of these tables and the specification in Appendix A shows that with the exception of the yttrium content of Heat 57006 of C129Y, all requirements were met. In this one deviation, the yttrium content was below the specified level of 0.1 percent (see Table 5). While undesirable, this deviation in chemistry was not expected to have a significant effect on the mechanical properties or weldability of this material. Accordingly, the material was accepted and used to determine the lot influence on properties in the as-coated condition.

The room-temperature tensile properties on all four heats of the as-received 0.015-inch-thick columbium-alloy sheet were determined using duplicate specimens (see Table 6 for results). As shown, the material from both heats of the two alloys showed good reproducibility in tensile properties and all of the material met the minimum properties specified. The BCL-determined properties for both heats of the Cb752 sheet also were in very good agreement with the certified test values on this material. By comparison, agreement between the BCL-determined and the certified values on the C129Y material was only fair. On checking the spread in property values with the producer, it was found that the tensile properties cited on the certification sheets did not necessarily represent test

TABLE 4. CERTIFIED ANALYSES AND TENSILE PROPERTIES FOR 0.015-INCH-GAGE COLUMBIUM-ALLOY SHEET, HEAT A

Element	Chemical Analyses[a] Cb752 Heat 770022	C129Y Heat 572038
W	10.1[b]	9.+[b]
Hf	435 ppm[b]	10.1[b]
Zr	2.7[b]	0.4[b]
Y	--	0.12[b]
C	40 ppm	40 ppm
O	70 ppm	90 ppm
N	40 ppm	35 ppm

Alloy	Heat No.	Room-Temperature Tensile Properties: Tensile Strength, psi	0.2% Offset Yield Strength, psi	Elongation, percent
Cb752	770022, Trans. No. 1	82,700	62,400	26.0
Cb752	770022, Trans. No. 2	82,500	65,500	26.0
C129Y	572038, Trans. No. 1	90,500	73,700	24.0
C129Y	572038, Trans. No. 2	92,900	75,100	26.0

(a) Weight percent unless indicated otherwise.
(b) Determined from ingot analysis.

TABLE 5. CERTIFIED ANALYSES FOR 0.015-INCH-GAGE COLUMBIUM-ALLOY SHEET, HEAT B

	Chemical Analyses[a]	
Element	Cb752 Heat 760055	C129Y Heat 57006
W	9.97[b]	10.45[b]
Hf	<100 ppm[b]	10.05[b]
Zr	2.80[b]	0.35[b]
Y	--	0.05[b]
C	40 ppm	75 ppm
O	170 ppm	95 ppm
N	100 ppm	81 ppm

(a) Weight percent unless indicated otherwise.
(b) Determined from ingot analysis.

TABLE 6. ROOM-TEMPERATURE TENSILE PROPERTIES OF AS-RECEIVED COLUMBIUM-ALLOY SHEETS

	Tensile Properties								
	BCL Values[a]			Min Specified[b]			Certified Values[b]		
Material	UTS, ksi	YS, ksi	Elong., % in 1 in.	UTS, ksi	YS, ksi	Elong., % in 1 in.	UTS, ksi	YS, ksi	Elong., % in 1 in.
Cb752, Heat 770022	81.9	64.6	28	75	55	20	82.7	62.4	26
	83.0	65.9	28	--	--	--	82.5	65.5	26
Cb752, Heat 760055	83.2	62.2	28	--	--	--	83.6	59.8	28
	83.6	61.2	26	--	--	--	83.3	61.8	25
C129Y, Heat 572038	86.4	68.1	28	80	60	20	90.5	73.7	24
	86.0	68.1	27	--	--	--	92.9	75.1	26
	88.3[b]	70.2[b]	26[b]						
	88.3[b]	68.8[b]	26[b]						
C129Y, Heat 57006	90.4	69.5	25	--	--	--	95.2	74.3	25
	88.3	67.9	23	--	--	--	95.5	76.4	23

(a) Longitudinal test direction, unless otherwise indicated.
(b) Transverse test direction.

results determined on the material supplied to BCL. Rather, the "certified" values may (and in this case, probably do) represent test results obtained on other sheets of the same heat which were processed to the same gage at the same time.

EXPERIMENTAL DETAILS

There were several facets to the experimental program as described in this section. Certain general features are stated in these introductory comments and more specific details in the subsections.

The aim on this program was to characterize the tensile properties of the two coating/alloy systems over the range of possible use temperatures. Specifically, the temperatures agreed on were room temperature, 1000, 1300, 1600, 1800, 2000, 2200, and 2400 F. The temperature range from 1000 to 1800 F was examined to assess the effects of reduced ductility, known to occur within this range, on design strengths of the materials.

Two kinds of specimens were used in this evaluation. The first was a simple subsize tensile specimen, utilized to obtain the basic tensile properties. The second was a transversely welded subsized tensile specimen (details subsequently given) employed to obtain some measure of the effect of welds on tensile properties of base material.

Unwelded specimens were tested in the as-coated condition and after 5, 10, and 30 cycles of a T/P condition representative of a shuttle environment (described subsequently); the welded specimens (coated after welding) were tested only in the as-coated condition.

To provide some assessment of variability in properties resulting from the coating process, the unwelded specimens were submitted to the coating vendors in the two batches. However, there is reason to believe that the coating operation was done on a subbatch basis, so that some reservation may be in order as to the significance of the analyses of these data on a batch-to-batch basis.

The gross allocations of specimens to the experimental studies were as follows:

Alloy	Number of As-Coated Base-Material Specimens		Number of As-Coated Base-Material Specimens (Heat A), Exposure Cycled as Indicated			Number of Welded, Coated (Heat A) Specimens	Total Number of Specimens
	Batch 1	Batch 2	5	10	30		
Cb752	80	80	40	40	40	80	360
C129Y	80	80	40	40	40	80	360

Since eight temperatures were involved in the tensile tests, ten specimens were tested at each temperature for the base material and welded specimens, whereas only five specimens were tested at each temperature for the exposure-cycled specimens. Further details on specimen allocation are given in the next subsection.

Specimen Allocation

Because of the number of variables that may influence the data analysis (heat-, sheet-, and coating-batch-variations; as well as the number of test temperatures and exposure conditions), further description of material and specimen allocation is in order.

Figure 2 and Figure 3 for Cb752 and C129Y, respectively, are helpful in this regard. Consider Figure 2 in some detail. The left-hand series of boxes identify sheet and heat numbers, and the average specimen dimensions in inches of the original substrate. The next column indicates quantities of specimens made from each sheet. For example, from Sheet 1 of Heat 770022, 60 specimens were fabricated in three groups. Groups 1 and 2 (see right column) were coated together in Batch 1 and actually can be considered to be the same processing. The ten specimens of Group 1 were kept separate as a group before, during, and after processing, and were used as control specimens for the coating thickness measurements subsequently described. The 20-specimen group from Sheet 1 was coated in Batch 2 processing. Upon return of this Batch 2 group, ten specimens were selected at random, identified as Group 3, and were subjected to the same detailed postcoating evaluation as a control group to provide assessment of batch statistics relative to coating thickness. Thus, there were four control groups (1, 9, 13 and 15) and two batch-check groups (3 and 11) for the R512E/Cb752

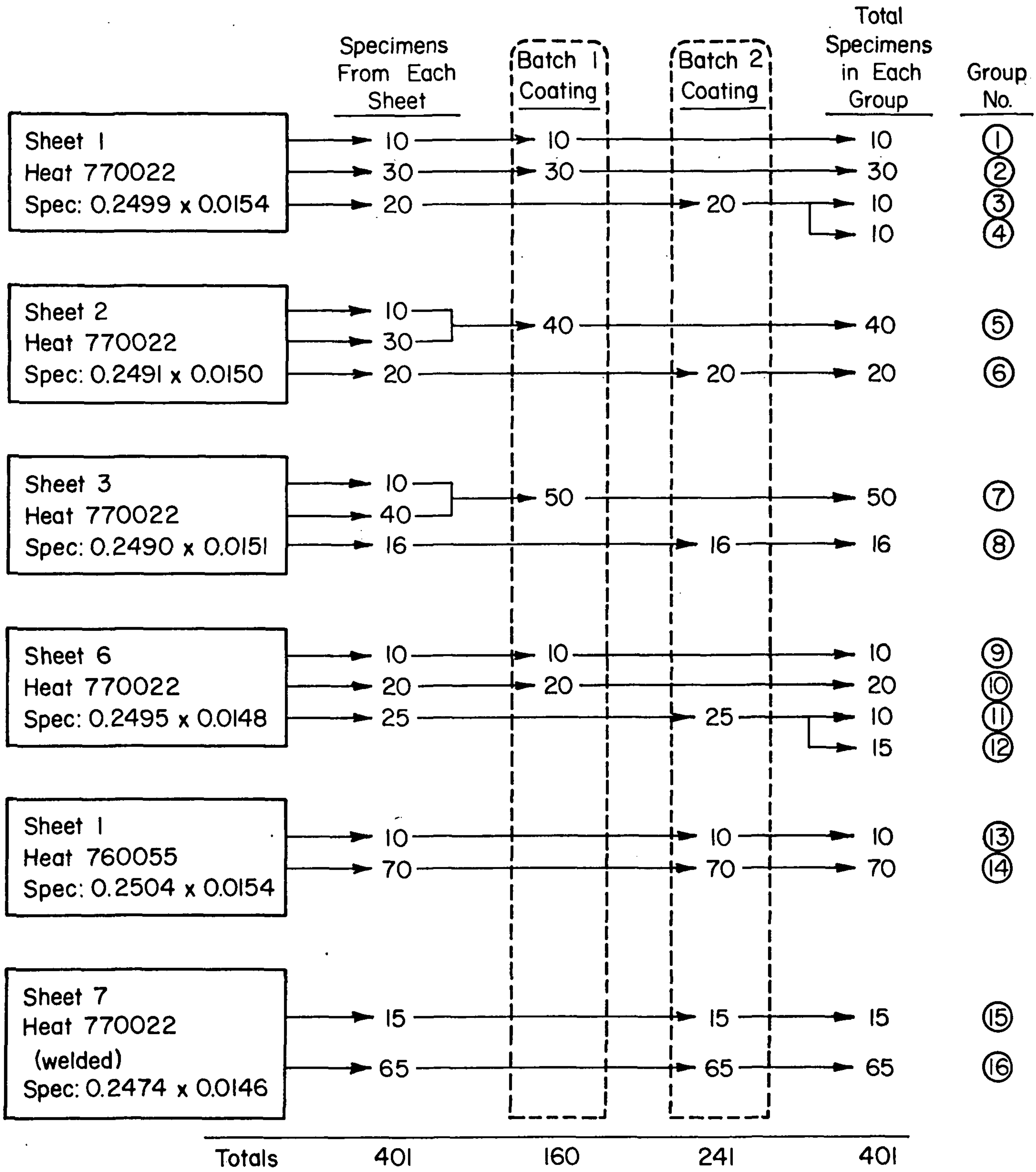

FIGURE 2. DEVELOPMENT OF R512E/Cb752 TEST GROUPS

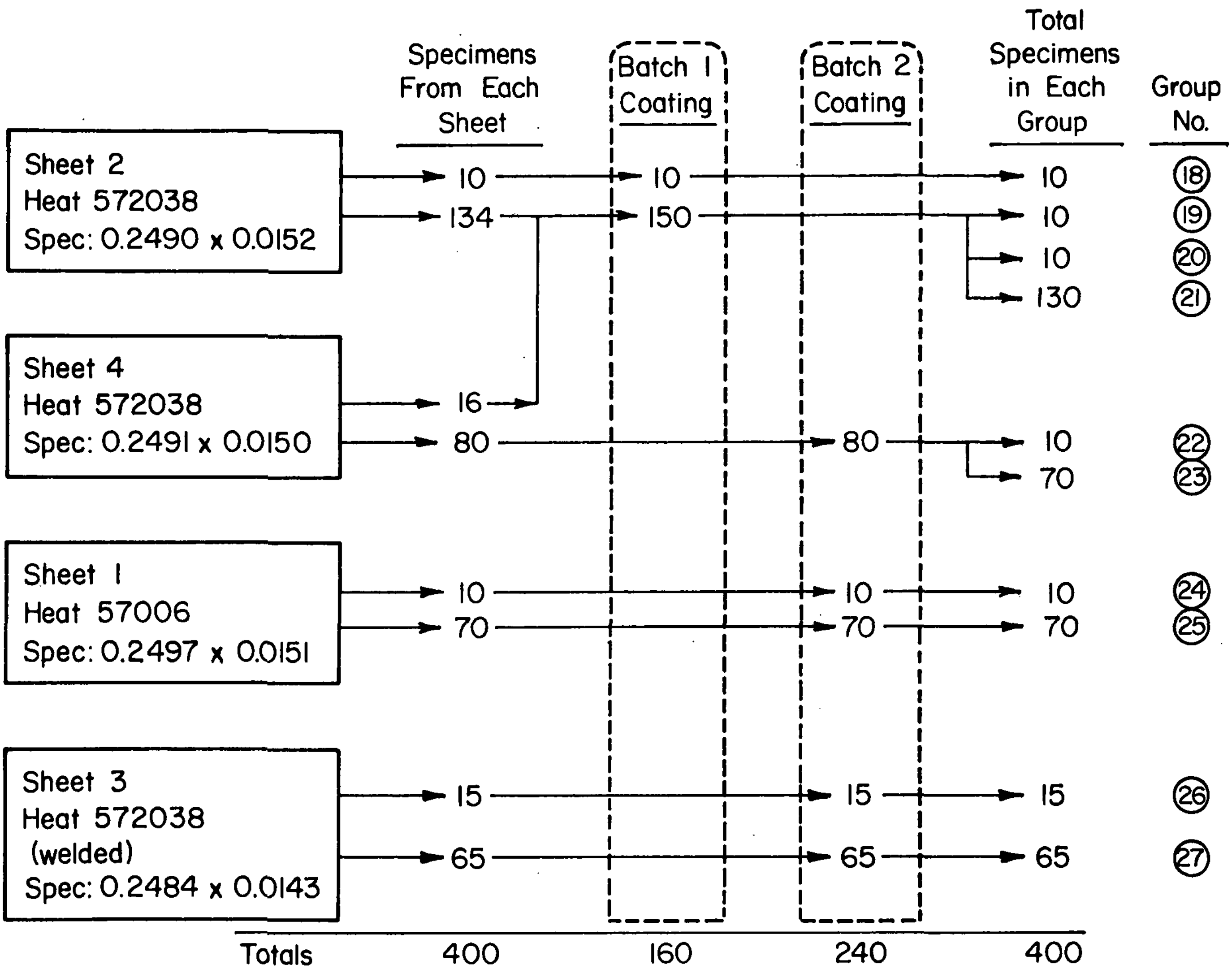

FIGURE 3. DEVELOPMENT OF VH109/C129Y TEST GROUPS

material. Similarly for VH109/C129Y (Figure 3) there were three control groups (18, 24 and 26) and three batch-check groups (19, 20 and 22).

Since the specimen yield from each sheet was quite different and allocations had to be made to provide two coating batches within one heat of each material, the final distribution of the unwelded specimens was complex. The decision was made that the second heat would be used only to compare coated-base-metal properties with those from the first heat. The unwelded, coated specimens from the two coating batches of the first heat of each material were allocated to the various test temperatures by distributing specimens from the various sheets among the temperatures on the assumption that sheet variations would be balanced out. Table 7 shows the allocation for R512E/Cb752 system; Table 8 shows that for VH109/C129Y. Note in these tables that welded specimens were allocated from one sheet of the first heat of each material and were coated in Batch 2.

Coated-Specimen Dimension Evaluation Procedures and Discussion

Three bases for reporting strength data are commonly used for coated columbium alloys, namely

(1) Load divided by cross-sectional area calculated on the basis of total dimensions of the coated specimen

(2) Load divided by the cross-sectional area calculated on the basis of specimen dimensions prior to coating

(3) Load divided by the cross-sectional area of the actual substrate remaining after coating.

Subsequently these bases are referred to as Methods 1, 2, and 3.

The first two methods are quite straightforward and need not consider the influence of the coating or the coating process. Because most (if not all) of the load (in tension) is supported by the substrate in coated columbium systems, the first two methods will result in conservative tensile strength data relative to the real strength of the load-bearing substrate. Of these, the second is the most widely used and was the method selected for data analyses in this program.

For thin columbium-alloy sheet, such as would be used in thermal protection system hardware, differences in strengths calculated by the above methods are substantial. This is because (1) typical 3-mil-thick coatings which do not support appreciable tensile loads comprise a significant portion of the cross-sectional area* and (2) during coating application, formation of protective coating compounds relies in part upon reaction with the substrate, thereby

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* For example, for 15-mil-thick columbium alloy sheet to which 3-mil-thick fused-slurry-silicide coatings are applied to both sides, the coating would comprise about 30 to 35 percent of the total material thickness.

TABLE 7. SPECIMEN ALLOCATION FOR AS-COATED R512E/Cb752

Heat No.	Sheet No.	Coating Batch	Group No.	Test Temperature, F RT	1000	1300	1600	1800	2000	2200	2400
				5 T/P Cycles							
770022	1	1	2	-	--	2	--	--	--	--	--
	1	2	3 & 4	-	--	3	--	--	--	--	--
	2	1	5	2	2	--	--	--	--	2	2
	2	2	6	3	--	--	--	--	--	--	3
	3	1	7	-	3	--	2	--	--	3	--
	3	2	8	-	--	--	3	--	--	--	--
	6	1	10	-	--	--	--	2	2	--	--
	6	2	12	-	--	--	--	3	3	--	--
				10 T/P Cycles							
770022	1	1	2	2	--	2	--	--	--	--	--
	1	2	3 & 4	3	--	3	--	--	--	--	--
	2	1	5	-	2	--	--	--	--	2	2
	2	2	6	-	--	--	--	--	--	--	3
	3	1	7	-	3	--	2	--	--	3	--
	3	2	8	-	--	--	3	--	--	--	--
	6	1	10	-	--	--	--	2	2	--	--
	6	2	12	-	--	--	--	3	3	--	--
				30 T/P Cycles							
770022	1	1	2	2	--	--	--	--	--	--	--
	1	2	3 & 4	3	--	--	--	--	--	--	--
	2	1	5	-	2	2	--	2	2	--	--
	2	2	6	-	--	--	--	--	--	1	2
	3	1	7	-	3	3	2	3	--	4	3
	3	2	8	-	--	--	3	--	--	--	--
	6	2	12	-	--	--	--	--	3	--	--
				Base Material							
770022	1	1	1 & 2	1	5	3	4	5	1	3	1
	1	2	3 & 4	-	1	2	1	1	--	--	--
	2	1	5	2	2	--	1	--	2	2	1
	2	2	6	2	1	--	--	--	2	--	2
	3	1	7	2	2	--	--	--	2	--	3
	3	2	8	2	1	--	--	--	2	--	2
	6	1	9 & 10	1	1	3	4	3	--	--	--
	6	2	11 & 12	-	1	2	1	2	--	2	--
760055	1	2	13 & 14	10	10	10	10	10	10	10	10
				Welded							
770022	7	2	15 & 16	10	10	10	10	10	10	10	10

TABLE 8. SPECIMEN ALLOCATION FOR AS-COATED VH109/C129Y

Heat No.	Sheet No.	Coating Batch	Group No.	Test Temperature, F							
				RT	1000	1300	1600	1800	2000	2200	2400
				Base Material							
572038	2	1	18	--	3	4	2	--	--	--	--
	2 & 4	1	19 - 21	5	2	1	3	5	5	5	5
	4	2	22 & 23	5	5	5	5	5	5	5	5
57006	1	2	24 & 25	10	10	10	10	10	10	10	10
				Welded							
572038	3	2	26 & 27	10	10	10	10	10	10	10	10
				Base Material, 5 T/P Cycles							
572038	2	1	21	3	4	3	3	3	3	4	5
	4	2	23	2	1	2	2	2	2	1	--
				Base Material, 10 T/P Cycles							
572038	2	1	21	3	3	4	3	3	4	4	4
	4	2	23	2	2	1	2	2	1	1	1
				Base Material, 30 T/P Cycles							
572038	2	1	21	3	3	4	3	5	5	1	3
	4	2	23	2	2	1	2	--	--	4	2

consuming some of the substrate and reducing the true load-bearing thickness of the composite. Thus, in measurements of strength for the purpose of determining the effects of coating or coating process upon the fundamental strength of the load-bearing substrate, the third of the above methods would provide the truest evaluation. Using data relative to the substrate consumption rates developed jointly in this program and under NAS8-26205[13], it would be expected that for a 3-mil-thick coating applied to both sides of 15-mil columbium-alloy sheet, apparent strengths indicated by the various methods of strength calculation (neglecting edge effects of tensile specimens) would be as follows:

Method	Relative Strength, percent
3	117
2	100
1	80

For strengths based on Method 2 used in this program, the true strength of the residual substrate would be 17 percent greater than the apparent strength.

All manufacturing processes have their associated tolerances which influence the design allowables. As described later in this report, the variability of mean-coating thickness within a coating lot, or "batch", and among coating batches was significant. For example, the overall mean-coating thicknesses and standard deviations for the coated columbium alloy systems investigated in this program were as follows:

System (Coating/Substrate)	Coating Thickness Statistics	
	$\bar{X}$	s
R512E/Cb752	3.41	0.27
VH109/C129Y	2.51	0.40

Vac-Hyd coatings were thinner than the Sylvania coatings and also displayed greater "within" and "among" batch variability. Because the total amount of substrate consumption varies with the coating thickness, on the basis of Method 2 strength evaluation which does not consider differences in coating thickness, the Vac-Hyd coating would have less of an effect on the apparent mean strength of C129Y than would the Sylvania coating upon that of Cb752. However, because of the relative standard deviations of coating thickness, greater variability in strengths of C129Y versus Cb752 would be expected.

From the above discussion, it should be clear that the method of strength computation causes a bias in the results that affect design strength values. Regardless of which method is used, it is important to appreciate just what is being measured and reported herein so that proper evaluation of design strength values can be conducted. Furthermore, since all three area measurements can be used, it was decided to conduct a detailed coating/substrate system dimensional analysis so that those using these data, based on original substrate dimensions, could conveniently convert to either of the other area bases.

As described previously, specimens from each material system were divided into a number of groups. Group-to-group variables included heat, sheet, and coating batch. Thickness evaluations within specimens, among specimens within a group, and among the various groups were made with

(1) Standard, flat-anvil micrometers

(2) Micrometers with pointed anvils

(3) A Model D-2 Dermitron Thickness tester, calibrated periodically during use against pedigreed coated columbium alloy specimens secured for this purpose.

In conjunction with efforts under contract NAS8-26205, several R512E/Cb752 and VH109/C129Y specimens covering a range of thickness (nominally from 1 to 5 mils) were obtained to establish micrometer and Dermitron standards in correlation with metallographically determined specimen, coating, and residual substrate thicknesses. Details of this calibration effort have been previously reported[14]. In addition, throughout this program, the shoulder sections of many tested specimens were measured and sectioned metallographically to provide additional correlation between micrometer, Dermitron, and metallographic thickness measurements.

Major findings of this study relative to thickness correlations are cited below:

(1) For the as-received, uncoated columbium-alloy sheet materials, measurements with flat micrometers, pointed micrometers, and metallographic (Filar eyepiece) gave equivalent results to within 0.1 mil.

(2) Flat and pointed-anvil micrometer measurements taken over the same areas showed consistent differences on the as-coated specimens. In a given 1/4-inch-square area, the minimum values observed with pointed micrometers were about 1 mil less than flat micrometer values for the R512E coating and about 1 mil (Batch 1 coating) and 2 mils (Batch 2 coating) less than the flat micrometer values for the VH109 coating. This difference is a measure of the relative roughness of the coatings. Correlated metallographic measurements checked to within 0.2 mil of the average of pointed micrometer measurements.

(3) Correlations between point micrometer, metallographic, and Dermitron-indicated coating thicknesses showed good correlation for Cb752, but the Dermitron-indicated thickness was consistently greater than true coating thickness determined metallographically for C129Y. This probably was a result of different roughness of the test specimens compared with the standard specimens used for Dermitron calibration. In any event, Dermitron measurements of coating thickness were less sensitive than micrometer readings (either type) or metallographically measured thickness.

(4) For coating thicknesses in the ranges obtained for this program (3.1 to 3.9 mils for R512E, 2.0 to 3.0 mils for VH109), this study showed the following factors for substrate consumption in the coating application process:

Coating	Substrate Consumption Factor F, mil of substrate consumed per mil of coating applied
R512E	0.36
VH109	0.37

Thus, for each specimen, point micrometers can be used in conjunction with knowledge of the initial substrate thickness and coated specimen thickness as follows:

$$CT_{true} = \frac{t_f - t_i}{2} + F\ (CT_{true}) \ ,$$

where CT_{true} = true coating thickness

t_f = specimen thickness after coating (metallograph or point micrometer; flat micrometer -1.0 mil for R512E, or flat micrometer -2.0 mils for VH109)

t_i = specimen thickness before coating (point or flat micrometer or metallographic determination)

F = Substrate consumption factor.

For the materials of concern in the respective thickness ranges for this program, this relationship can be simplified to

R512E/Cb752: $CT_{true} = 0.781\ (t_f - t_i)$

VH109/C129Y: $CT_{true} = 0.794\ (t_f - t_i)$.

The unreacted substrate thickness, t_s, is as follows:

$$t_s = t_f - 2CT_{true}.$$

Specific evaluation procedures followed in this program to classify coating thickness statistics were as outlined below.

(1) For each sheet of material, select at random a group of ten machined tensile specimens. For each of these measure and record three values of thickness and width to the nearest 0.1 mil, as determined by both flat and pointed micrometers. Compute mean and standard deviations of

substrate thickness. For all other specimens, measure thickness and width at the center of the specimen with flat micrometers. (In all cases, "other" specimens fit the established sheet statistics.)

(2) For selected sheets, the ten randomly selected specimens were kept separate from other groups (see Figures 2 and 3) from the particular sheet throughout processing. These were the "control" groups. In general, other specimens were kept separate by sheet. At least one control group of each material was included in each of the two coating batches.

(3) After return from the coating vendor, the control groups were again measured with both flat and pointed micrometers in at least three places to establish coating thickness statistics. For the balance of specimens from any given sheet, several groups of ten specimens each were selected at random, and accorded the same measurement and statistical treatment as the control groups as a further check on batch statistics. Specimens not selected for either "control groups" or "batch check" purposes were measured with flat micrometers only at the specimen centers.

(4) Each specimen was measured at the center on each side with the Dermitron as a check for gross side-to-side variation in coating thickness. Within the sensitivity limits of the instrument, no gross side-to-side variation was noted.

For specimens that were neither control nor batch-check groups, flat micrometers rather than pointed micrometers were the major criterion for coating thickness. This is because pointed micrometer determinations require a real searching for minimum thickness values. Because of the small area and relatively high measurement stress, point measurements require considerably greater operator precision and a delicate "touch". The point-to-flat micrometer correlations established in control and batch-check group evaluations allowed good confidence in estimates of thickness based on flat micrometer measurements, and flat micrometer measurements were converted to point micrometer, or true coated thickness values.

The net result of the detailed evaluation procedures described was the determination of mean and standard deviations of thickness for each coating group for (1) as-received, uncoated material, (2) coated material, and, (3) vis relationships just described, coating thickness. These data, reported in the "Results" section, provide a basis for calculation of strength and variability of strength for each group using any of the three methods of strength calculation. They further provide a basis for estimating the extent of strength variability that is caused by variability in coating (hence substrate) thickness.

Welding Procedures

Procedures were developed and evaluated for butt welding of 0.015-inch-thick Cb752 and C129Y sheet specimens. All specimen preparation and welding was conducted in a clean-room laboratory. Welds were made using the gas-tungsten-arc process with direct current and straight polarity conditions (electrode negative). Tungsten electrodes containing 1 percent ThO_2 were used. After preliminary experiments, the following parameters were fixed:

- Electrode diameter: 0.040 inch
- Clamping bar separation: 1/4 inch
- Arc length: 0.040 inch
- Travel speed: 30 inches per minute
- Electrode extension beyond torch collet: 3/4 inch.

The weld data utilizing the above parameters are shown in Table 9.

TABLE 9. COLUMBIUM-ALLOY WELDING DATA

Sample No.	Welding Current, amperes	Welding Voltage, volts	Energy Input, watt-min/inch	Face Width, inch	Root Width, inch	Pressure Rise Before Welding, torr/min x 10^5
752-5	57.0	17.0	32.3	3/32-1/8	5/64-1/8	3.3
752-6	56.0	17.0	31.8	5/64	5/64	9.6
752-7	59.0	16.5	32.4	3/32	1/16	10.2
752-8	56.0	17.5	32.7	1/16	5/64	9.9
752-9	56.5	17.0	32.0	3/32	1/16	9.2
752-10	56.0	18.0	33.6	3/32	1/16	10.9
752-11	54.5	18.5	33.6	3/32	1/16	11.2
129-4	57.5	16.5	31.6	3/32	1/16	9.2
129-5	60.0	16.0	32.0	3/32	1/16	--
129-6	56.0	16.7	31.2	3/32	3/32	8.93
129-7	59.0	15.7	30.9	3/32	3/32	8.92
129-8	58.0	16.4	31.7	3/32	3/32	8.59
129-9	57.5	15.8	30.3	3/32	3/32	8.59
129-10	55.5	16.6	30.7	3/32	3/32	9.59

Following a small number of initial welds, two full-length welds between 1/2-inch-wide sheets were made (129-3 and 752-4) in order to qualify the final welding procedures. The specimen edges were ground, and the pieces then were cleaned by the following method: wiped with acetone and Kimwipes; etched in a solution of 55 percent H_2O, 20 percent HNO_3, 15 percent HF, 10 percent H_2SO_4 (by volume) at room temperature; rinsed in cold tap water; rinsed in boiling demineralized and double distilled water for 3 minutes; rinsed with ethyl alcohol; and dried in still air.

The specimens were installed in a fixture with the butt joint centered on a 1/16-inch-radius groove in a copper backing plate. Copper-backed bars were clamped on top of the specimens with 1/8 inch between each clamping bar and the weld joint (a clamping-bar separation of 1/4 inch). The sheets and fixture were installed in an 8-cubic-foot, stainless steel welding chamber and the chamber was evacuated to 2-3 x 10^{-6} torr for 2 hours prior to backfilling with helium and welding.

Immediately before welding, the pressure rise in the chamber was measured over a 3-minute period, with the high-vacuum valve closed, and recorded on the data sheet. The average value of these measurements, 8.8 x 10^{-5} torr/min, indicates that actual and virtual leaks were not introducing any significant amount of contamination into the welding chamber. After the pressure rise measurement, the chamber was reevacuated to 3 x 10^{-6} torr, or less, before reclosing the high-vacuum valve and backfilling the chamber to atmospheric pressure with ultrahigh-purity helium. The impurity analysis (by volume) for this helium was reported by the supplier (Matheson) as

CO_2 - 0.0181 ppm	Ar - 0.0030 ppm
O_2 - 0.0426 ppm	Ne - 0.3561 ppm
H_2 - 0.0025 ppm	H_2O - 0.1 ppm .
N_2 - 0.4411 ppm	

The moisture content of 0.1 ppm corresponds to a dew point of -130 F.

After welding, the current and voltage were read from the recorder traces and entered on the data sheet, the weld face and root width were recorded, and the welds were radiographed and fluorescent-penetrant inspected.

The two qualification welds were further evaluated by bend testing longitudinal weld specimens from each end of both welds in a dry ice-acetone solution (-108 F) with a 1/64-inch-radius male die (1T bend radius). The female bend die had an included angle of 105°. The bend axis was perpendicular to the weld direction. Examination of the tensile side of the bend specimens at 30X with a binocular microscope did not reveal any surface cracks and the welds were concluded to have satisfactory quality. Transverse metallographic specimens from both ends of the welds also were prepared. On the basis of these evaluations, the 14 final butt welds were made with the same procedures.

Single bend test specimens were prepared from each of these 14 welded sheets and all were successfully bent over a 1/64-inch radius in a dry ice-alcohol solution (-97 F) using the same conditions stated above. The balance of these materials was committed to the preparation of tensile test specimens in which the weld orientation was transverse to the tension axis, as well as to the final sheet rolling direction.

Metallographic examination on sections through each of these 14 welded sheets showed the geometry of the butt welds to be consistent for each alloy, but uniquely different between the two alloys, as shown in Figure 4. Thus, all of the C129Y joints showed an overall thickening in section to an average value of 106 percent of the base metal thickness. In contrast, the thickness of the Cb752 joints decreased to an average of 97 percent of base-metal thickness at each side of the weld zone and increased thereafter to an average of 109 percent of base-metal thickness at the center of the weld. This thinning of the weld zone of the Cb752 material suggested that its maximum weld efficiency might not exceed 97 percent of the base-metal properties.

To provide some idea of the width of the weld and heat-affected zones for correlation with failure locations, a detailed evaluation was made on cross-sections through the welds. Thus it was possible to delineate the location of the fusion line and the termination of the heat-affected zone (HAZ). Three measures were used for this termination: (1) the difference in the nature of the etched surface, (2) the distance where the grain size decreased to that of the basis material, and (3) the distance where the hardness had decreased to that of the basis material.

The following data summarize these measurements:

Characteristic	Distance from Weld Centerline, inch Cb752	C129Y
Fusion Line	0.031	0.030
HAZ, Etching	0.043	0.040
HAZ, Grain Size	0.046	0.049
HAZ, Hardness	0.060	0.060

From these measurements, one concludes that the HAZ extended to about 1/16 inch from the centerline of the weld for both alloys.

Specimen Fabrication

The specimen used for this program was a subsize specimen as shown in Figure 5.

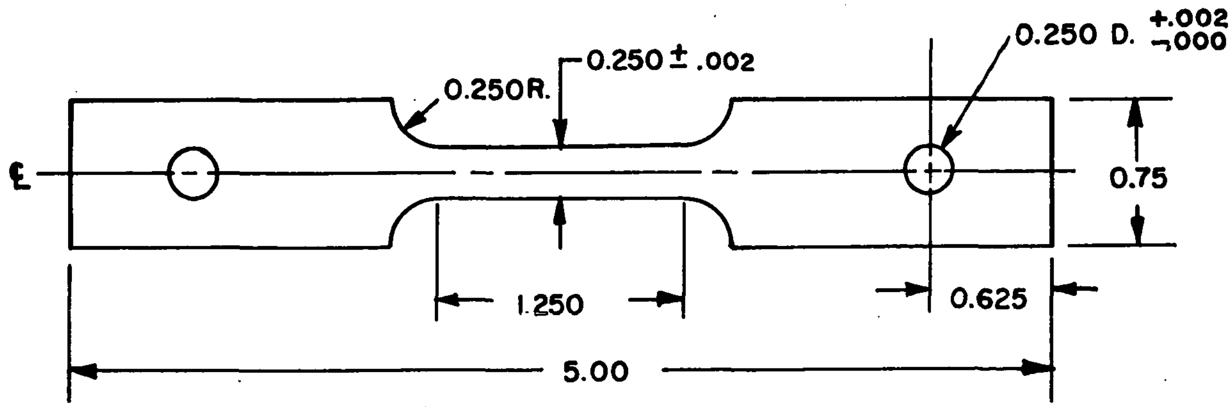
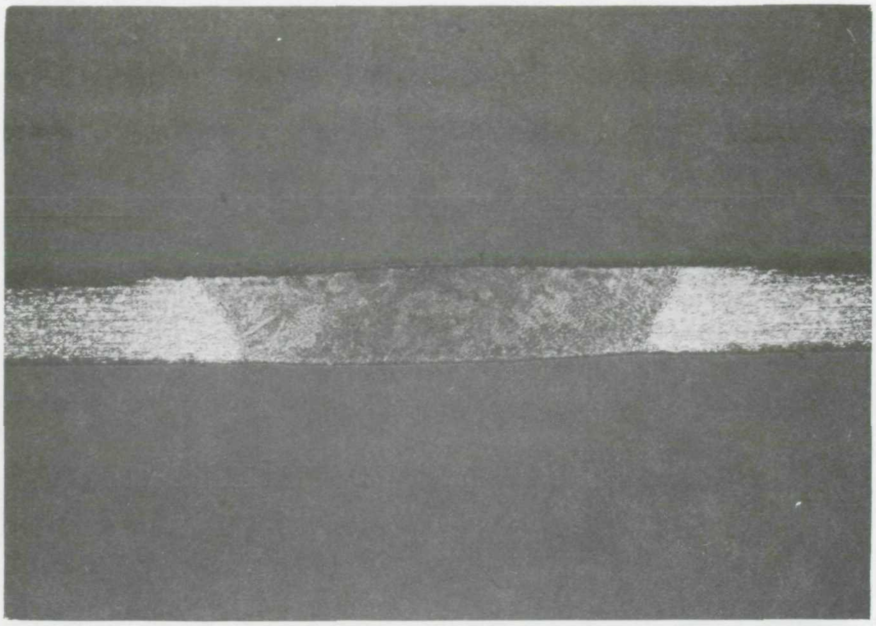
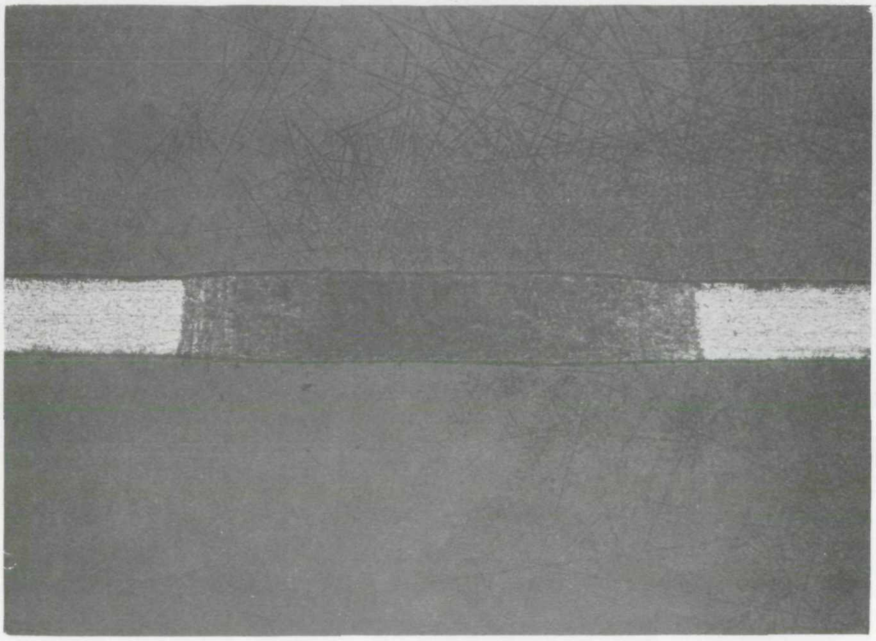


FIGURE 5. COLUMBIUM TENSILE SPECIMEN



40X 9F723

a. Cb752 Weld



40X 9F724

b. C129Y Weld

FIGURE 4. SECTIONS THROUGH REPRESENTATIVE WELDED JOINTS

Eight hundred and four tensile test specimens were machined to this standard test configuration. For all specimens, the final sheet rolling direction was maintained parallel to the tensile specimen axis. When welds were incorporated, these were located centrally in the reduced test section with the weld orientation transverse to the tensile axis. The identities and end uses of the heats represented are given below:

Number of Specimens[a]	Heat Designation	End Use
320[b]	A	Cyclic oxidation exposure effects
160	A	Heat-to-heat variation, as-coated condition, base-line statistics
160	B	Heat-to-heat variation, as-coated condition, base-line statistics
164	A	As-welded condition statistics.

(a) Half of each group represents Cb752 specimens for R512E coating and half represents C129Y specimens for VH109 coating.
(b) Includes 40 extra specimens of each alloy.

Eight hundred* of these specimens were prepared for coating using the following procedure:

(1) Abrasive tumbling in an Al_2O_3 water slurry for 2 hours to radius specimen edges

(2) Acid pickling in a 20 percent HNO_3, 5 percent HF, 75 percent water solution

(3) Water rinsing

(4) Alcohol rinsing and air drying.

Four hundred each Cb752 and C129Y specimens were shipped to Sylvania Electric Products and Vac-Hyd Processing Corporation, respectively, in two batches of 160 and 240 each (see Figures 2 and 3).

Thermal/Pressure Cycling Procedures

In order to provide a temperature/pressure (T/P) cycle simulating a mission for a columbium-containing structure, the T/P profile shown in Figure 6

* Two each welded specimens of Cb752 and C129Y were held for tensile testing in the uncoated condition for base line comparison purposes.

was planned for cyclic-exposure tests. The following paragraphs describe the equipment and procedures used.

The major pieces of equipment used in the T/P cycling exposures are identified schematically in Figure 7. The specimens were suspended vertically inside a 2-inch-ID by 12-inch-long quartz chamber and induction heated. The top of the chamber was provided with a valved, air-bleed line. Chamber pressure was controlled automatically by preprogrammed adjustments of a 1/4-inch-diameter valve located in the vacuum line between the bottom of the furnace chamber and a mechanical pump with a maximum pumping speed of 3.54 ft^3/min (Edward's High Speed Rotary Pump, Model ED-100).

The specimens were heated by radiation from a 1.2-inch-ID by 2-inch-long ATJ Grade graphite susceptor. Up to seven tensile specimens were accomodated simultaneously in a given sequence of cyclic exposures. These were suspended on a high-purity alumina support rod using alumina spacers between specimens. In order to prevent overheating of the quartz walls, as well as to improve temperature uniformity, the graphite susceptor and specimen support rod were contained within an open-topped, 1-3/4-inch-diameter by 6-1/8-inch-long high-purity alumina crucible (not shown in Figure 7). The bottom of the crucible was provided with a 0.5-inch-diameter hole to allow the in-leaking air to flow directly past the specimens being exposed.

For monitoring and controlling temperature, two Pt/Pt-10Rh thermocouples were suspended centrally among the given samples constituting a run. Calibration runs showed that the temperature variation over a vertical distance of 1-1/2 inches around the center of the specimens was $\pm$ 20 F at 2500 F. One thermocouple was part of a closed-loop temperature control system. The desired temperature profile was obtained from the output of an arbitrary analog function generator (Datatrak) programmed to follow the predetermined time-temperature waveform. Figure 8 illustrates several time-temperature cycles as reproduced from the original recorded data from the first series of 5 cycles on the VH109/C129Y specimens.

Mechanical-Property Test Procedures

Specimen dimensions and preparation have been described in earlier sections of this report. In general, the test methods for evaluation of refractory sheet described in MAB-192-M have been followed.

In order to process several hundred specimens in a reasonable time frame, all elevated-temperature test specimens were brought to temperature by direct induction heating using a Lepel 2.5-kw generator. Three different load coil designs were used and the generator frequency was varied from 5 to 8 MHz in order to achieve uniform heating and efficient power transfer to the specimens through the entire range of test temperatures. The use of the induction unit necessitated the containment of the test frame in a shielded enclosure to prevent the broadcasting of RF that would interfere with the operation of electronic laboratory equipment.

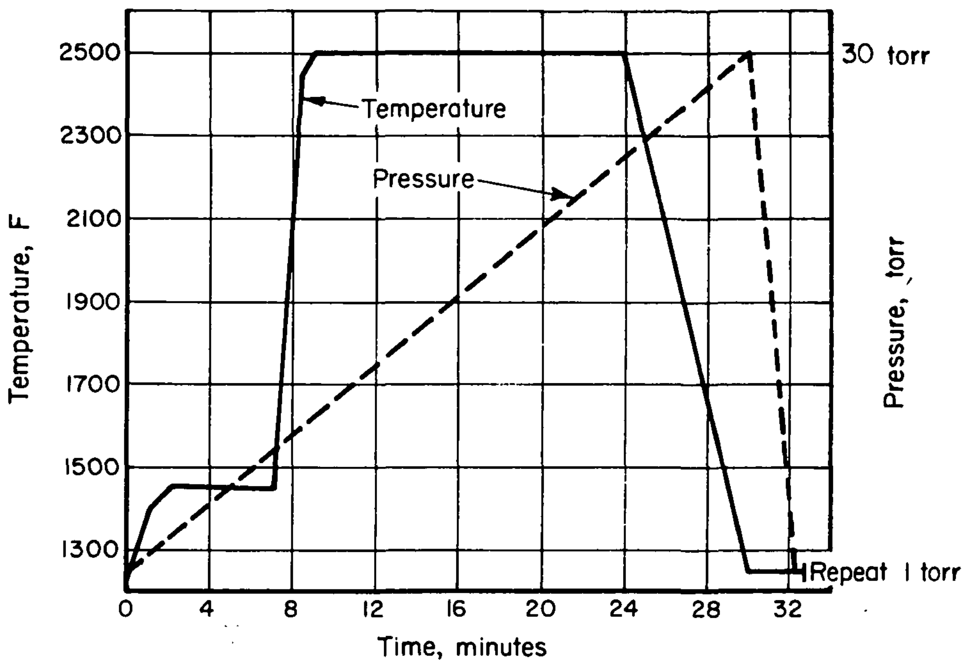


FIGURE 6. TEMPERATURE AND PRESSURE CYCLE PLAN FOR COATED COLUMBIUM SPECIMENS

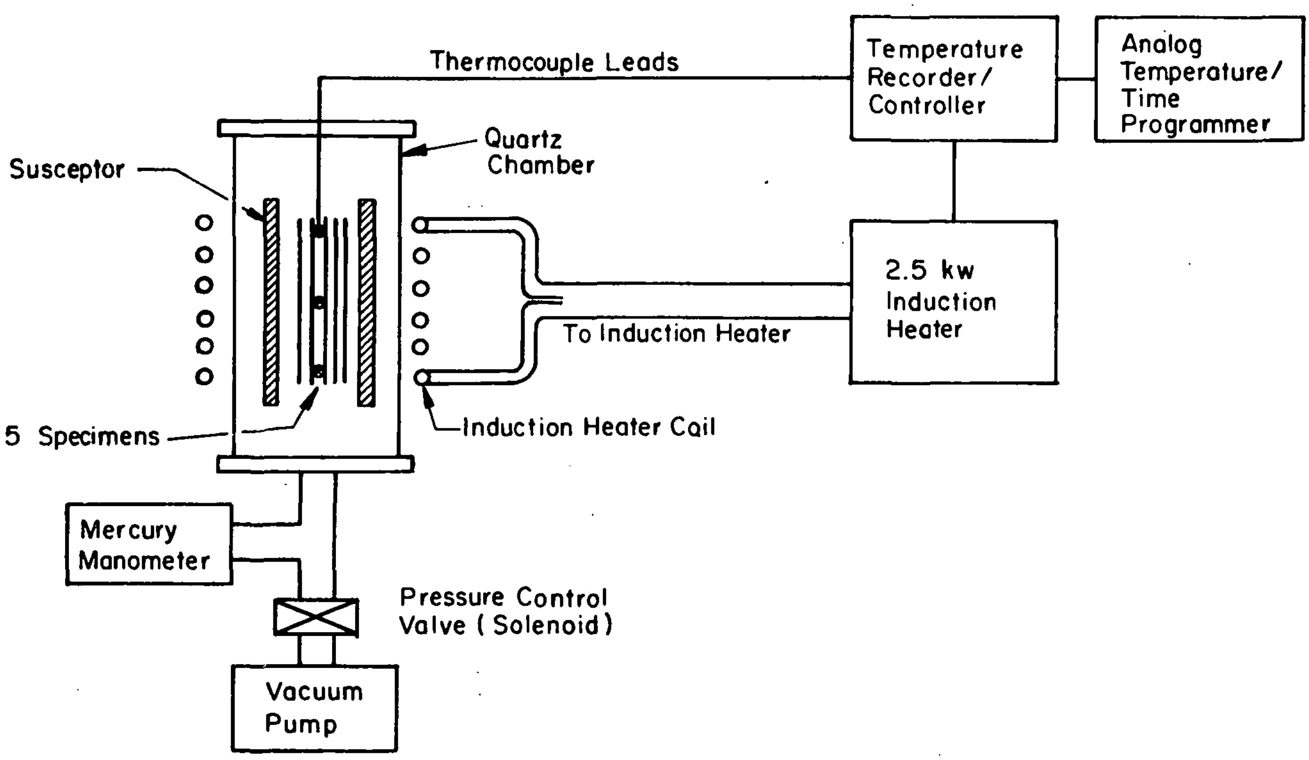


FIGURE 7. THERMAL CYCLING SETUP FOR COLUMBIUM TESTS

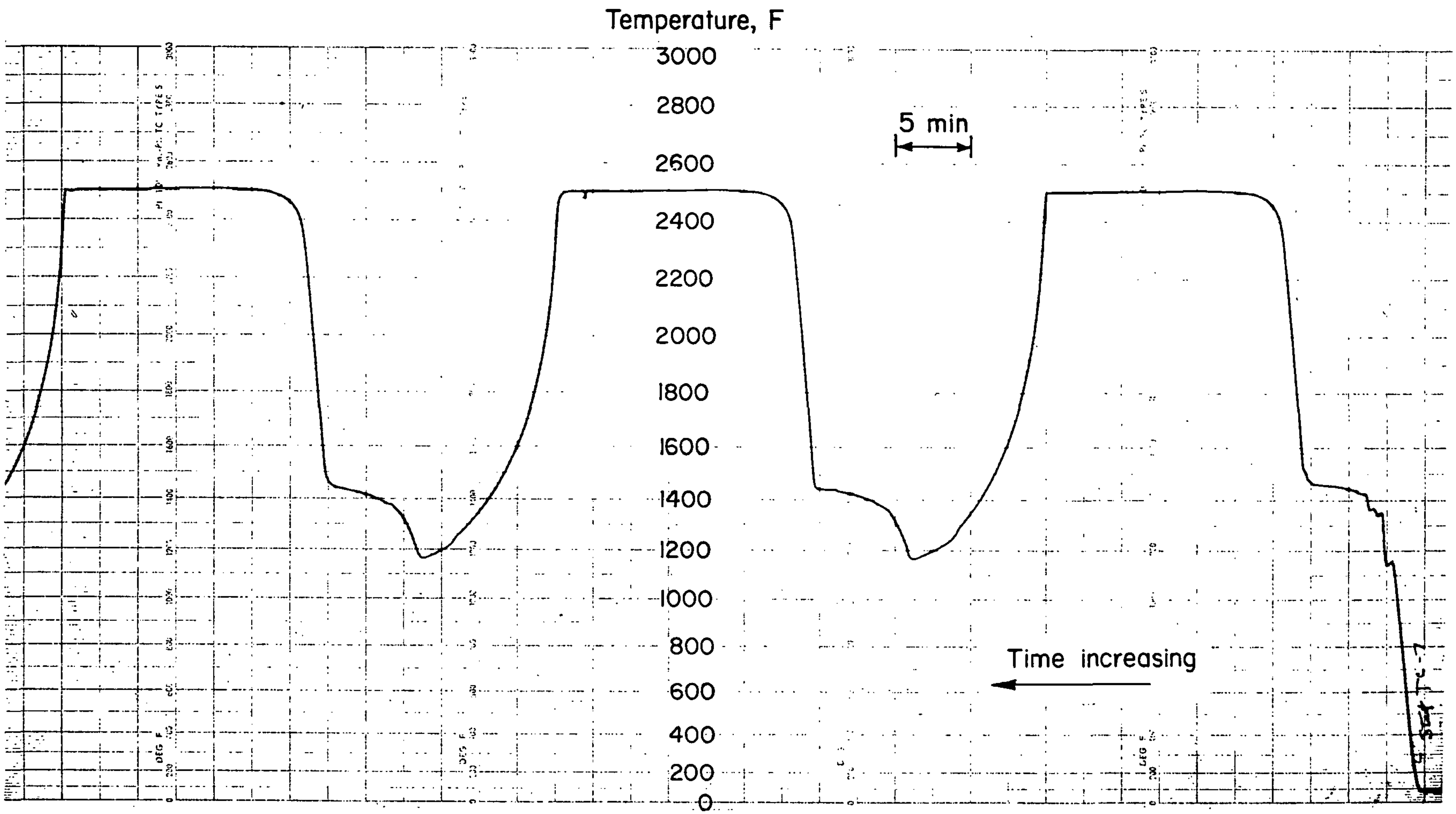


FIGURE 8. ACTUAL TEMPERATURE PROFILE TAKEN FROM FIRST SERIES OF 5 T/P EXPOSURES

Because of the reactivity of the coatings, a noncontacting infrared pyrometer temperature-measuring system (Ircon Model 300L) was used for temperature control. The conditioned output signal of the pyrometer (0-100 mv) supplied a control signal to a Leeds and Northrup 3-action C.A.T. Controller/Recorder. The temperature controller, in turn, supplied a 0-5-ma control signal to an SCR power package (Norbatrol) which regulated the plate voltage to the oscillator tube in the induction heating generator, thus regulating plate current in the load coil.

Two methods of temperature calibration were used. At 1600 F and below, temperature check specimens of both materials were instrumented with Type K thermocouples (Chromel/Alumel, ISA special calibration) and the output of these thermocouples, read on a Leeds and Northrup Type 8693-2 double-range long-scale temperature potentiometer, was used to calibrate the infrared pyrometer.

In order to instrument the calibration specimens, the coating was first removed from one side. Previously prepared 0.003- by 1/4- by 3/8-inch stainless steel shims, to which thermocouples were capacitive-discharge welded, were in turn capacitive-discharge welded to the specimens so that the thermocouples were located at specimen center and at both ends of the gage length. The check specimen, installed with the coated side facing the infrared pyrometer, was then heated to the desired temperature and the output of the pyrometer was adjusted to maintain the desired thermocouple-indicated temperature. This technique provided for an emittance correction for use of the IR control pyrometer at the desired temperatures. The temperature at the top and bottom of the gage length was then checked and, if necessary, fine adjustments were made in heating coil height or spacing so as to minimize the temperature differential along the gage length. This technique was used to calibrate unexposed material and also 5-, 10-, and 30-cycle exposed materials of each coating/substrate system.

Above 1600 F, a Leeds and Northrup 8636-C brightness pyrometer was used to monitor temperature on the side of the specimen opposite the control pyrometer. The calibration of the brightness pyrometer was checked on a tungsten lamp source which was calibrated using a standard-brightness optical pyrometer calibrated by the National Bureau of Standards. Calibration records show that, over the duration of this program, no significant changes in calibration occurred. The tungsten lamp source also was used to correct the effect of the RF screen which covered the sight port in the RF shielding. After adjusting the output of the control pyrometer to achieve temperature control at the temperature indicated by the brightness pryometer (with no emittance correction), the temperature distribution along the gage length was checked and adjustments in coil position and spacing were made, as necessary, to minimize the temperature differential along the gage length of the specimen.

The brightness optical pyrometer was selected as a standard because of several factors. At the operating wavelength of this device ($\sim$ 0.65 micron), a change in emissivity of 10 percent admits an error in indicated temperature of only approximately 1 percent. The infrared pyrometer, operating at 2-2.65 microns, would yield an error of approximately 3 percent. Thus, with the use of the brightness pyrometer for calibration and also for periodic temperature checks, if one accepts the commonly estimated emittance values between 0.6 and 0.9 for the systems/conditions being tested, the maximum error in temperature that might be expected would be about 100 F at a test temperature of 2400 F. Thus, for a stated temperature of 2400 F, the actual specimen temperature may have been as great as 2500 F. In point of fact, the rough surface of the coatings, their gray color, and the reflected light from the surrounding induction heating coils should act to increase the effective emissivity of the specimens and decrease the error in indicated temperature to within 2 percent of actual temperature.

Using the above outlined temperature calibration and control procedures resulted in approximately a ± 5 F temperature distribution (along the gage length) at 1800 F and within ± 10 F above 1800 F.

For the actual test, the heating rate was about 15 seconds to maximum at all temperatures. The specimens were held at temperature for approximately one minute to achieve equilibrium prior to testing.

In order to obtain stress versus strain data from the mechanical tests over the complete range of temperature, two extensometer techniques were employed. At room temperature, a strain gage extensometer (Instron, 1-inch gage length, 10 percent maximum range) was attached directly to the specimen and load versus elongation curves were obtained using an X-Y recorder.

Because of the heating method, coating on the specimens, and conduction of heat from the specimen, the use of the conventional clip-on-type extensometer having metal gripping elements was not possible at the elevated temperatures. Therefore, various methods for measuring strain were examined. A modification of BCL's extensometer design for low-cycle fatigue studies was finally selected. With this system, shown in Figures 9 and 10, two high-purity aluminum-oxide probes

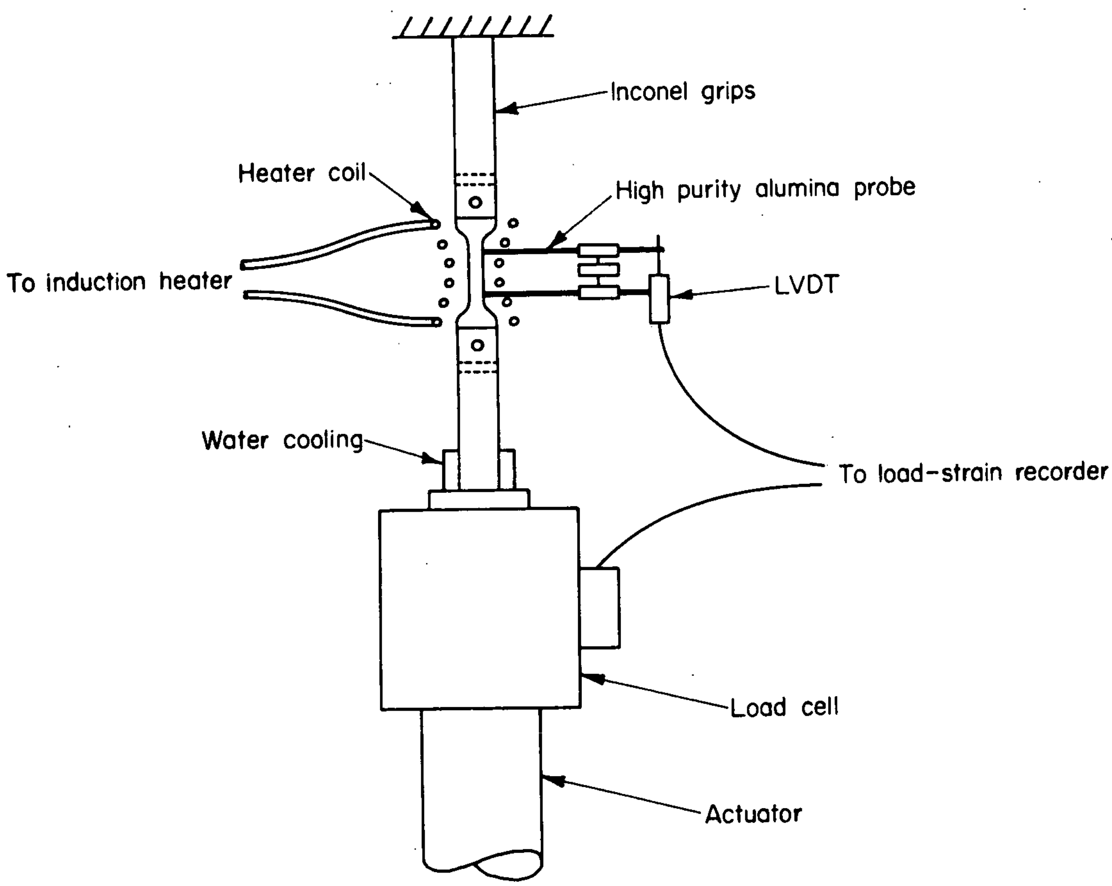


FIGURE 9. SCHEMATIC OF SETUP FOR TENSILE TESTING OF COLUMBIUM ALLOYS

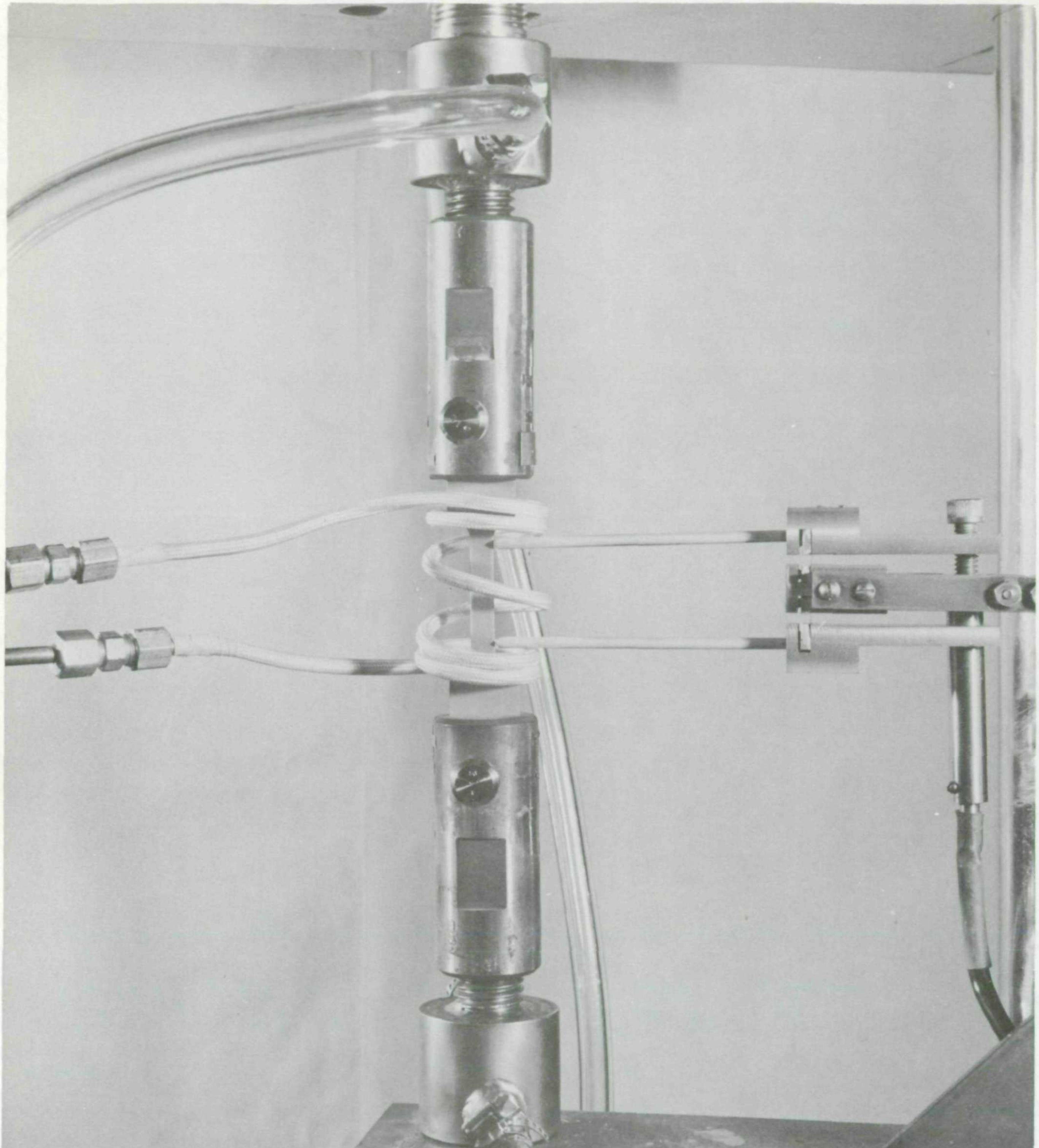


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FIGURE 10. SETUP FOR TENSILE TESTS OF COLUMBIUM ALLOYS AT ELEVATED TEMPERATURES

were arranged to maintain contact against the specimen as the specimen elongated. The pressure was sufficient to maintain contact and to track, but not great enough to damage the coating. The other ends of the arms, joined to the center block by a spring pivot, held the linear variable differential transformer (LVDT) required to determine specimen strain. The calibration was checked periodically and found to be within 0.00010-inch deflection in the 1-inch gage length. This accuracy of strain measurement was equivalent to Class B1, ASTM E83-67.

Although the operation of this extensometer was checked and found to be reproducible within the same accuracy limits, some problems were encountered in the actual data acquisition phase. It is believed that the specimen condition, i.e., warpage in all three directions, was the primary reason for the inability to obtain stress-strain curves for all specimens. This is discussed further in another section of this report.

The tensile tests were conducted using a test frame containing a 2.5-kip-capacity electrohydraulic closed-loop controlled actuator. Load readout was provided through a 5,000-pound capacity load cell in series with the specimen and actuator. (The load cell is shown at the bottom of Figures 9 and 10. Note the water cooling provided on the test fixture to keep the load cell at or very near room temperature.) A 500-pound (or less, depending upon ultimate load requirements) full-scale load range was used. This provided a load accuracy of 0.2 percent. The strain rate for all elevated temperature tests was 0.05 in./in./min. At room temperature, a strain rate of 0.005 in./in./min was used to a strain somewhat beyond 0.2 percent offset strain, and 0.05 in./in./min thereafter to failure.

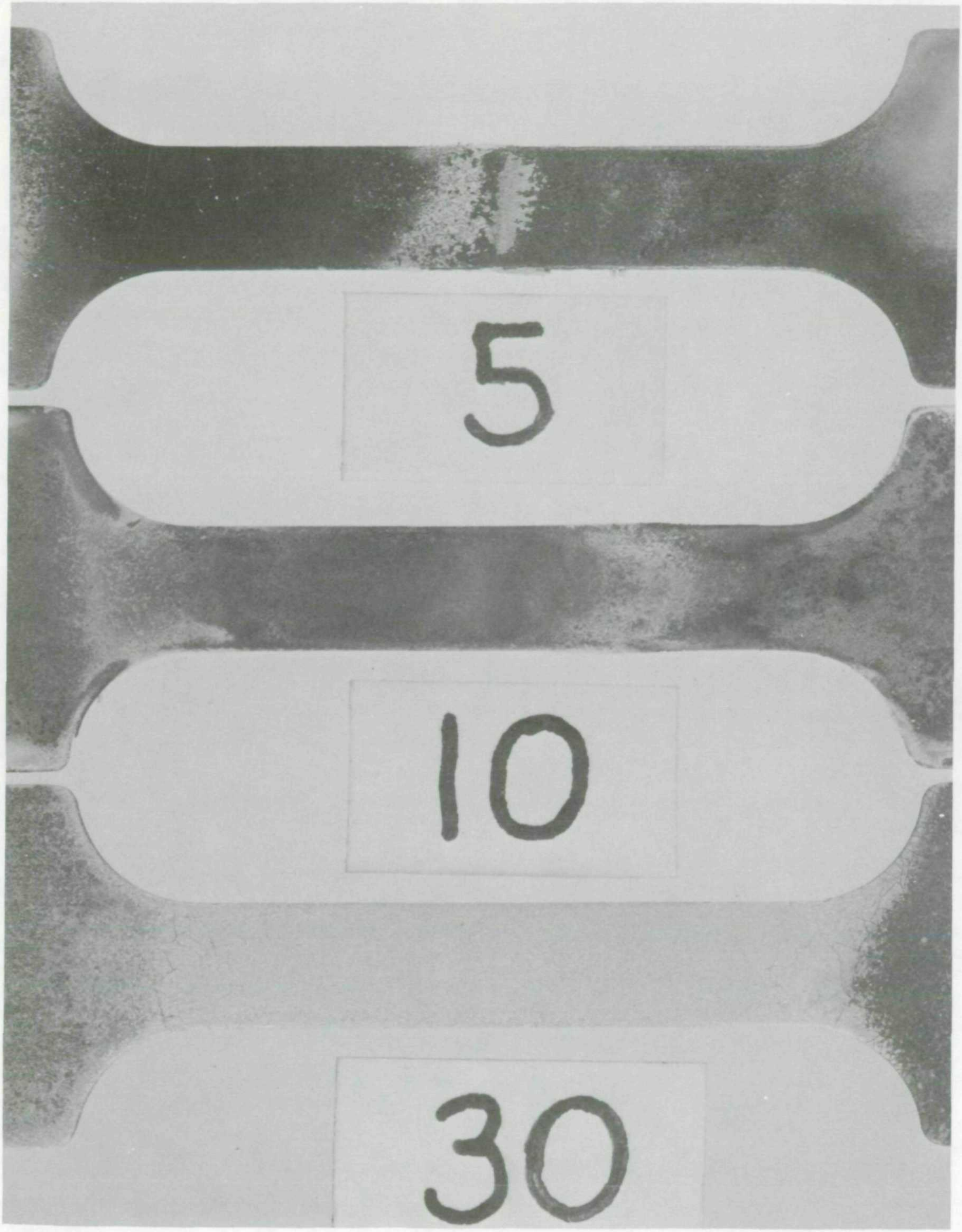
RESULTS

Visual Observations

All specimens allotted to T/P cycling were examined after 5, 10, or 30 exposures prior to further testing. In no case was there any visual evidence of coating failure as a result of the cyclic oxidation exposure. That is, none of these specimens exhibited a gross accumulation of oxidation products or erosion which could be associated with the formation and growth of oxides on the underlying Cb752 or C129Y alloy substrates. Figures 11 and 12 show the appearance of typical R512E/Cb752 and VH109/C129Y specimens after exposures of 5, 10, and 30 cycles.

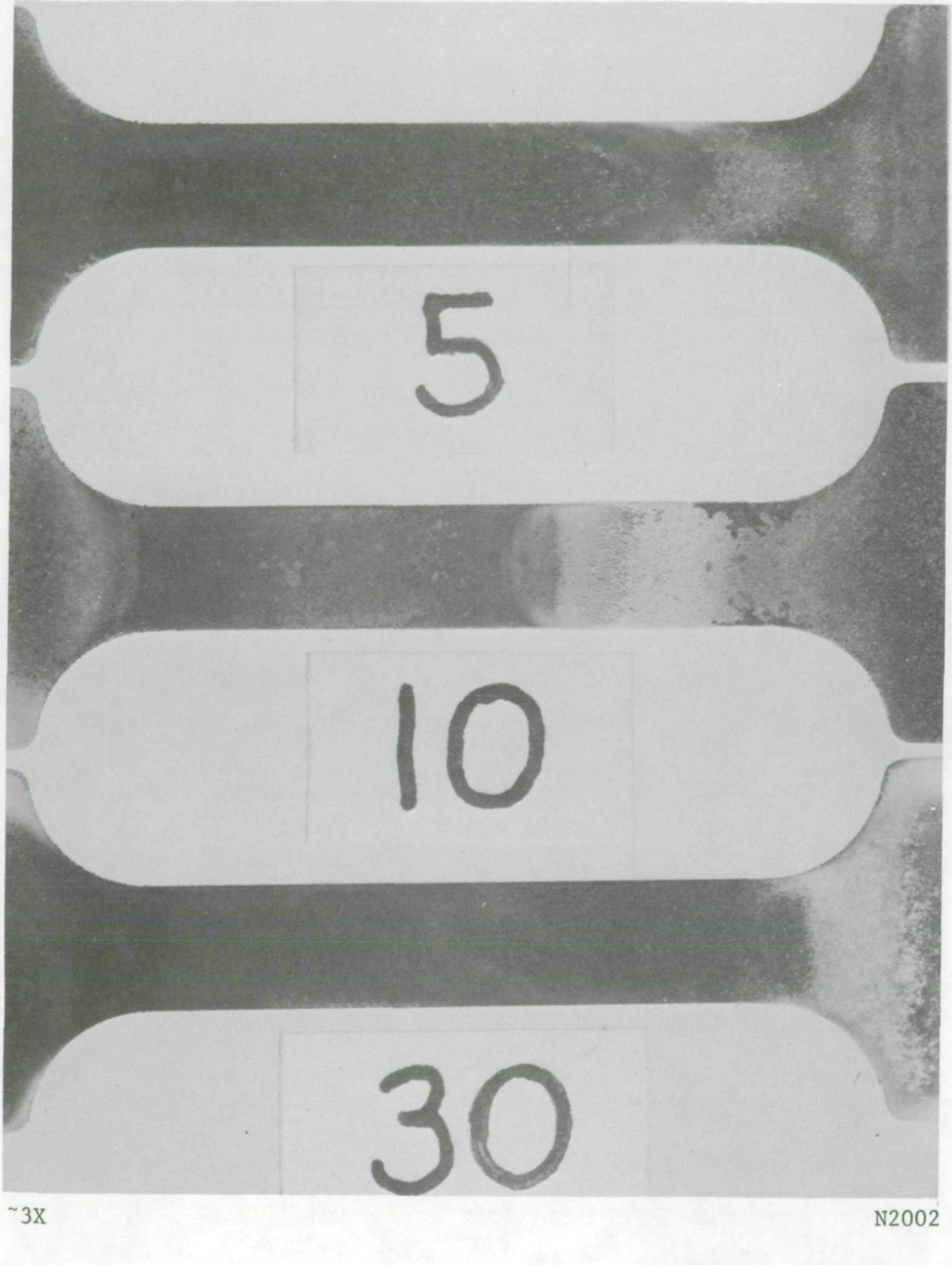
As expected, progressive oxidation of both the R512E and VH109 coatings did occur with continued cyclic exposures. Some observations on the appearance changes of these coated specimens as a function of their cyclic exposure history are summarized as follows:

(1) Some localized spalling of the coating oxidation product occurred on isolated specimens representing both alloy coating systems. The extent of this spalling was about the same for both systems after 5 and 10 cycles but



~3X N2001

FIGURE 11. APPEARANCE OF TYPICAL R512E/Cb752 SPECIMENS AFTER EXPOSURES OF 5, 10, AND 30 CYCLES



~3X N2002

FIGURE 12. APPEARANCE OF TYPICAL VH109/C129Y SPECIMENS AFTER EXPOSURES OF 5, 10, AND 30 CYCLES

appeared to increase for the VH109/C129Y specimens after 30 cycles as compared with the R512E/Cb752 specimens.

(2) After 5 and 10 cycles, the predominating color for specimens in both systems was flat black. However, areas of yellowish tan also appeared to characterize many of the R512E/Cb752 specimens while a greenish oxide also tended to characterize many of the VH109/C129Y specimens.

(3) After 30 cycles, the VH109/C129Y specimens were predominantly flat black in color. In contrast, the R512E/Cb752 tended to present a yellowish tan, heavily oxidized appearance. Most of the R512E coatings on the 30-cycle specimens also displayed a craze-cracking pattern as illustrated in Figure 11.

Specimens representing both systems also showed an accumulation of a white, powdery oxidation product on the shoulder areas, well away from their uniformly heated reduced sections. This had the appearance of being a condensed deposit on the cooler areas of the specimens. A spectrographic analysis of this material (taken from two R512E/Cb752 specimens after 5 cycles) showed it was predominantly silicon* and was tentatively identified as SiO_2. On the basis of this and other data described later, it was concluded that the silica shoulder deposit represents essentially a recombined condensate of silicon-monoxide which was effectively distilled from the surface at the center of the reduced section of the individual specimens during the peak 2500 F exposure temperature period of each cycle. This transfer was obviously facilitated by the low pressures which were maintained during the cyclic exposures. As discussed later, it is suspected that the actual oxygen pressure was much lower than the $\sim$ 5 torr maximum intended during the maximum temperature portion of the exposure.

Only minor metallographic evidence of silicide depletion was observed on any of ten coated specimens (five each R512E/Cb752 and VH109/C129Y) which were examined after 10 cyclic exposures. However, the five R512E/Cb752 specimens which had received 30 cyclic exposures definitely displayed gross coating porosity, indication of high silicon losses, in the reduced section. Several VH109/C129Y specimens exposed for 30 cycles prior to metallographic examination showed much less gross coating porosity than present in most R512E/Cb752 specimens.

No unusual incidents were noted during the subsequent elevated-temperature testing in air of any of the coated specimens which had received 5 or 10 cyclic exposures prior to testing. However, some unusual problems with temperature control were encountered during the attempted tensile testing of the coated specimens which had previously received 30 cyclic exposures. Specifically, the problem test temperatures identified were as shown below:

Coating System	Problem Test Temperature, F
R512E/Cb752	1000, 1300, 1600, 1800
VH109/C129Y	1300, 1600

* The deposit contained less than 1 percent of columbium, iron, chromium, and zirconium.

Specimens precycled 30 times and induction heated to the above temperatures in air overshot the target temperature even though the correct power setting to obtain each temperature was used. This exothermic rise to temperature terminated with gross oxidation of the substrates. Surprisingly, at higher temperatures this exothermic temperature rise did not occur and no gross substrate oxidation was noted.

In studying this phenomenon, a side experiment was performed which consisted of simply reheating two tensile test specimens (one each R512E/Cb752 and VH109/C129Y to about 1400 F) in an air furnace. Both specimens had previously received 30 cyclic exposures at 2400 F. It was observed that the optical temperatures (i.e., color) at the reduced center sections of both specimens did not equilibrate with the furnace but overshot the furnace temperature by a substantial amount. On cooling to room temperature, it was found that the center thickness of both specimens had been reduced by about 30 percent as a result of the coating and substrate oxidation reactions which had apparently ensued.

In essence, these combined experiences suggest that the composition and protective quality of both the R512E and VH109 coatings are subject to change as a result of continued exposure to the high-temperature/low-pressure cycling conditions used in this program. No evidence was obtained that either the composition or protective quality of either coating had been changed significantly after ten cyclic exposures. However, in air, the protective quality of both coatings had deteriorated significantly after 30 cyclic exposures, particularly at temperatures in the region of 1000 to 1800 F.

Specimen Dimension Analyses

For R512E/Cb752 and VH109/C129Y, Tables 10 and 11 summarize the results of measurements of initial thickness of the various sheets, final thickness statistics (mean and standard deviation) for each group, and coating thicknesses (mean and standard deviations) derived from formulae cited in the procedures section. Control data on welded specimens were recorded from locations at the extremities of the reduced gage section (first row for Groups 15 and 26), as well as directly over the weld bead. Upon receipt of specimens of coating Batch 2, Group 27 (VH109/C129Y, welded) contained 66 specimens, whereas only 65 welded specimens had been shipped. Group 25 from Batch 2 was short one specimen. It was not possible to find and correct this misplaced specimen before testing. Test results and posttest metallography clearly showed that Specimen 1 from Group 27, tested at room temperature, was the misplaced specimen.

From this general summary compilation, data were selected to examine the influence of heat, coating batch, and sheet variables. These comparisons are presented in Tables 12 and 13 for the R512E/Cb752 and VH109/C129Y systems, respectively.

Both the general and grouped summary data show, in most cases, that the variability in thickness, or standard deviation values, associated with the VH109/C129Y system is greater than that for the R512E/Cb752 system. It is also generally apparent that the variability in thickness is somewhat greater for coated than for uncoated materials.

TABLE 10. SUMMARY OF AVERAGE COATING THICKNESS MEASUREMENTS ON R512E/Cb752 SPECIMENS

Group No.(a)	Sheet No.	Coating Batch	No. of Spec.	No. of Values	Micrometer Data: Init. Sheet Thickness, mils $\bar{x}$	s	Coated Thickness, mils: Flat $\bar{x}$	s	Pointed $\bar{x}$(b)	s	Coating Thickness, mils $\bar{x}$(b)	s(b)	Dermitron Data: No. of Values	Coating Thickness, mils $\bar{x}$	s
							Heat 770022-Cb752								
1C	1	1	10	30	15.4	0.33	20.4	0.49	19.5	0.40	3.2	0.28	40	3.5	0.35
2	1	1	30	30	--	--	20.2	0.48	(19.2)	--	(3.0)	(0.34)	60	3.5	0.21
3BC	1	2	10	30	--	--	20.4	0.47	19.5	0.36	3.2	0.25	20	3.2	0.11
4	1	2	10	10	--	--	20.1	0.25	(19.1)	--	(2.9)	(0.18)	20	3.1	0.18
5	2	1	40	40	15.0	0.07	20.4	0.33	(19.4)	--	(3.4)	(0.23)	80	3.6	0.25
6	2	2	20	20	--	--	19.8	0.33	(19.8)	--	(3.7)	(0.23)	40	3.2	0.25
7	3	1	50	50	15.1	0.13	20.5	0.38	(19.5)	--	(3.4)	(0.27)	100	4.0	0.38
8	3	2	16	16	--	--	20.3	0.32	(19.3)	--	(3.3)	(0.22)	32	3.3	0.21
9C	6	1	10	30	14.8	0.21	19.9	0.28	18.9	0.40	3.2	0.28	40	3.4	0.42
10	6	1	20	20	--	--	20.0	0.21	(19.0)	--	(3.3)	(0.15)	40	3.3	0.21
11BC	6	2	10	30	--	--	19.9	0.44	18.8	0.36	3.1	0.25	20	3.3	0.31
12	6	2	15	15	--	--	19.8	0.37	(18.8)	--	(3.1)	(0.26)	30	3.0	0.28
							Heat 760055-Cb752								
13C	1	2	10	30	15.4	0.17	20.6	0.40	19.6	0.38	3.3	0.27	40	3.3	0.25
14	1	2	70	70	--	--	20.6	0.40	(19.6)	--	(3.3)	(0.28)	140	3.6	0.35
							Heat 770022-Cb752, Welded								
15C	7	2	15	30(c)	14.6	0.16	19.9	0.62	19.1	0.52	3.5	0.36	60	3.2	0.42
				15(d)	15.8	0.16	22.1	0.47	20.9	0.89	4.1	0.62	30	4.3	0.46
16	7	2	65	65(d)	--	--	22.1	0.51	(21.1)	--	(4.1)	(0.36)	130	4.6	0.60

(a) C signifies control group; BC signifies batch-check group.

(b) Values in parentheses estimated on the basis of data from control groups from same heats and coating lots.

(c) Values determined on parent metal.

(d) Values determined on weld bead.

TABLE 11. SUMMARY OF AVERAGE COATING THICKNESS MEASUREMENTS ON VH109/C129Y SPECIMENS

Group No.(a)	Sheet No.	Coating Batch	No. of Spec.	No. of Values	Micrometer Data: Init. Sheet Thickness, mils $\bar{x}$	s	Coated Thickness, mils: Flat $\bar{x}$	s	Pointed $\bar{x}$(b)	s	Coating Thickness, mils $\bar{x}$(b)	s(b)	Dermitron Data: No. of Values	Coating Thickness, $\bar{x}$, mils
							Heat 572038-C129Y							
18C	2	1	10	30	15.2	0.37	20.8	0.44	19.0	0.42	3.0	0.28	40	4.0
19BC	2+4	1	10	30	--	--	19.7	0.42	18.1	0.47	2.3	0.31	20	3.6
20BC	2+4	1	10	30	--	--	19.6	0.35	17.8	0.30	2.1	0.20	40	3.6
21	2+4	1	130	130	--	--	20.2	0.65	(18.4)	--	(2.5)	(0.44)	260	3.9
22BC	4	2	10	30	15.0	0.16	21.3	0.59	19.2	0.64	3.3	0.43	40	5.1
23	4	2	70	70	--	--	20.9	0.66	(18.6)	--	(2.9)	(0.44)	140	4.5
							Heat 57006-C129Y							
24C	1	2	10	30	15.1	0.17	20.0	0.92	18.0	0.59	2.3	0.40	40	3.8
25	1	2	69	69	--	--	21.0	0.67	(18.7)	--	(2.9)	(0.45)	138	4.5
							Heat 572038-C129Y, Welded							
26C	3	2	15	30(c)	14.3	0.17	19.4	0.48	17.3	0.35	2.4	0.23	60	4.0
				15(d)	15.4	0.31	20.0	0.49	18.0	0.46	2.1	0.31	30	4.0
27	3	2	66	66(d)	--	--	21.0	0.60	(18.7)	--	(2.6)	(0.40)	132	4.5

(a) C signifies control group; BC signifies batch-check group.

(b) Values in parentheses estimated on basis of data from control groups from same heats and coating lots.

(c) Values determined on parent metal.

(d) Values determined on weld bead.

TABLE 12. ANALYSIS OF INFLUENCE OF VARIABLES ON THICKNESS OF R512E/Cb752

Variable	Level	Initial Thickness, mils		Coated Thickness, mils		Coating Thickness, mils		Mean Residual Substrate Thickness, mils
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	
HEAT	770022[a]	15.1	0.22	19.2	0.37	3.2	0.26	12.7
	760055	15.4	0.17	19.6	0.39	3.3	0.28	13.0
COATING	Batch 1	15.1	0.22	19.3	0.38	3.3	0.26	12.7
	Batch 2[a]	15.1	0.20	19.4	0.39	3.3	0.27	12.8
SHEET (HEAT 770022)	1	15.4	0.33	19.4	0.40	3.1	0.25	13.2
	2	15.0	0.07	19.5	0.33	3.5	0.23	12.5
	3	15.1	0.13	19.5	0.37	3.4	0.26	12.7
	6	14.8	0.21	18.9	0.35	3.3	0.24	12.5
	7[a]	14.6	0.16	19.1	0.52	3.5	0.36	12.1

(a) Parent metal measurements only on welded specimens.

TABLE 13. ANALYSIS OF INFLUENCE OF VARIABLES ON THICKNESS OF VH109/C129Y

Variable	Level	Initial Thickness, mils		Coated Thickness, mils		Coating Thickness, mils		Mean Residual Substrate Thickness, mils
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	
HEAT	572038[a]	15.0	0.31	18.5	0.45	2.6	0.39	13.0
	57006	15.1	0.17	18.5	0.59	2.7	0.42	13.0
COATING	Batch 1	15.2	0.37	18.4	0.40	2.5	0.38	13.4
	Batch 2[a]	15.0	0.17	18.5	0.54	2.8	0.42	12.8
SHEET (HEAT 572038)	2[b]	15.2	0.37	18.4	0.41	2.5	0.38	13.4
	3[a]	14.3	0.17	17.3	0.35	2.4	0.23	12.5
	4	15.0	0.16	18.8	0.64	3.0	0.47	12.7

(a) Parent metal measurements only on welded specimens.

(b) Includes groups 19, 20, and 21 which contained a few specimens from Sheet 4.

From examination of the grouped data (Tables 12 and 13), it is particularly evident that heat, batch, or sheet variables have little effect upon the variability of the R512E coating, but these variables are suggested to be mildly significant for the VH109 coating. However, the generalized data indicate that differences in standard deviation between groups within a heat, batch, or sheet are as great as among these variables.

The mean thickness values shown in Tables 12 and 13 are the thickness values that would be used in determining strengths as described in the preceding section of this report. Thus, mean coated thickness would be used for "Method 1", mean initial thickness for "Method 2", and mean residual thickness for "Method 3". Comparisons between these mean values grouped according to heat, coating batch, and sheet are accordingly of interest. Because of relationships described previously, differences in mean coating thickness among heats, coating batches, or sheets can affect the differences between means for total coated or residual substrate thicknesses versus the differences observed initially for the uncoated substrate.

In this context, for R512E/Cb752, it is apparent that regardless of method of strength calculation, no between-heat or between-coating batch strength differences should be observed because of specimen size differences. Thus, as described in this report, the heat-to-heat difference observed for R512E/Cb752 undoubtedly reflects a genuine difference in the substrate properties *per se*. This is not necessarily the case for sheet-to-sheet property variation, however. For example, consider the mean thicknesses for Sheets 1 and 7. Initially, the difference was about 5 percent, with Sheet 1 exhibiting the greater thickness. For Sheet 1, a coating with mean thickness of 3.1 mils was applied; for Sheet 7, the coating thickness averaged 3.5 mils. This reduced the difference between means of coated thickness to less than 2 percent, but increased the difference between residual substrate mean thickness to about 9 percent. Since the residual substrate is the load-bearing component, it is likely that strengths based on Method 1 calculations would show a significant difference between tests of Sheet 1 and Sheet 7 that would be attributable to specimen geometry effects. Calculations based on Method 2 would be less likely to show a difference, and Method 3 strength comparisons should show only normal experimental scatter unless real sheet-to-sheet substrate material differences were present.

Similarly, for VH109/C129Y, between-heat differences in mean thicknesses are negligible. Batch-to-batch mean differences vary from +0.5 percent to -4.7 percent for coated thickness versus residual substrate thickness. Because of the higher standard deviations for VH109/C129Y, it is unlikely that this 5.2 percent disparity would be found significant. In comparing Sheet 2 with Sheet 4, the disparity from "coated" to "residual" mean thickness is 7.6 percent which might result in a significant difference for this system when Method 1 strength basis is used. The thickness disparity is reduced to 4.2 percent with Method 2 evaluation; this probably would not be significant.

In addition to the major strength differences related to the method of strength calculation, there also can be second-order influences engendered by state-of-the-art coating variability. In general, the analysis of geometry effects has shown that these second-order affects are probably of little significance when strengths are computed on the basis of Method 2 or Method 3 as previously defined. With Method 1 computations, some significant second order effects would be expected.

In addition to the preceding analyses of as-coated specimen dimensions, five room-temperature tensile test specimens representing both coating systems were sectioned through their fractured, reduced test sections after being subjected to 10 and 30 cycle exposures, respectively. The average thicknesses of the innermost subsilicide coating layers on these specimens were determined metallographically and compared with these as-coated subsilicide coating layer thicknesses to determine the subsilicide growth rates. These values were then related to the substrate consumption which occurred during cyclic exposure by the relationship

$$7\ Cb + 3\ CbSi_2 \Rightarrow 2\ Cb_5Si_3 .$$

The corresponding substrate consumption and area correction factors computed are given below:

Coating System	Precycled Substrate Thickness, mil	No. of Cyclic Exposures	Total Substrate Consumption, mil	Area Correction Factor
R512E/Cb752	12.4	10	0.30	0.976
		30	0.60	0.952
VH109/C129Y	12.9	10	0.27	0.979
		30	0.53	0.959

These correction factors show that for both coating systems after 10 cyclic exposures, the strength values based on the preexposed residual substrate thicknesses (i.e., the precyclic exposure condition) would be about 2 percent lower as a result of the additional substrate consumption which occurred. For specimens with 30 cyclic exposures, the corresponding strength degradations expected would be 4.1 and 4.8 percent for the VH109/C129Y and R512E/Cb752 specimens, respectively. The percent losses in strength based on Method 2 calculations would be slightly greater.

Tensile Test Data

All tensile test data for the entire test program are assembled in the tabular display of Appendix B. As stated previously, load and strain were recorded to a level beyond the 0.2 percent offset yield strength during each tensile test. In addition, a readout of the maximum load was also obtained from each recording. From these charts it was possible to obtain the values necessary to encode the data as follows for subsequent computer analysis:

GR - Group number
SP - Specimen number
WID - Specimen width
THK - Specimen thickness
U-LD - Ultimate Load
Y-LD - Yield load
EL - Elongation.

The coating/alloy system, specimen condition, and temperature also were recorded on each card.

The group numbers refer to the test allocation plan shown in Figures 2 and 3.

Specimen width and thickness are reported in thousandths of inches and represent the dimensions measured by flat micrometers at the center of each specimen prior to the test. Thus, using the average thickness measurements for each group described previously, one can compute for each specimen the residual substrate thickness, if strength in terms of residual substrate thickness is desired.

The ultimate load is the maximum load attained during a test. The yield load was taken from the load-extension trace at 0.2 percent offset. One of the problems associated with the tensile testing and analysis of the resulting load-extension curves was the condition of the specimens after coating. Since the materials were so thin, when coated, the resulting specimens all were somewhat out of plane. This warpage made it a difficult process to establish the initial modulus line in order to subsequently establish the yield strength. However, since the load-strain traces in the region of yield strength were fairly flat, it is believed the reported yield loads have not been affected much by the uncertainty in modulus.

Elongation is reported to the nearest tenth of a percent. At the moderately high temperatures, particularly where the ductility was a minimum, it was sometimes difficult to adduce any elongation. For those cases, no values are reported in the printout.

DATA ANALYSIS AND DISCUSSION

General Remarks

According to Chapter 9 of MIL-HDBK-5B[15], there are a number of options available for the computation of room- and elevated-temperature design allowables. Where large amounts of data are available, such as frequently found for room-temperature tensile properties, the allowables can be computed directly. These inputs may come from a variety of producers and represent different heats or lots, thickness ranges, and product forms. One of the first tasks then is an analysis applying statistical significance tests to determine whether a data collection is homogeneous (namely one population) or is made up of several subpopulations which cannot be combined. Whichever is the case--one or several populations--each such population of values then is analyzed further.

The second step is to determine whether each population under consideration is normally distributed. MIL-HDBK-5B suggests the use of the "Chi-squared" test or a cumulative distribution plot to establish normality. If the population is normal, then the direct calculation of A and B design allowables is carried out based on the procedures for a normal distribution with the requirement that a minimum of 100 pieces of data be available representing at least 10 heats or lots of material in the population of values. In the event that the population of values is nonnormally distributed, Chapter 9 suggests the use of a nonparametric analysis procedure which requires at least 300 values in the population in order to establish an A value.

The establishment of A and B values at elevated temperatures also can be done by direct computation as described above. Usually, however, the available data at elevated temperature are so much less than that available at room temperature, that the data requirements (in terms of numbers of specimens and heats) are rarely met. Thus, an alternative approach is provided in Chapter 9.

This alternative approach requires at each temperature several tests from at least five heats which can be paired with comparable data at room temperature. In application, for each heat the ratio of the average strength at temperature, T_1, divided by the average strength for the same heat at room temperature is computed. This is done for each heat and for each temperature. Then at each temperature, the following steps are taken:

(1) Compute the sample statistics ($\overline{R}$, the mean value; and s, the standard deviation) of the ratios.

(2) Determine the lower confidence limit for the mean ratio.

(3) Use the lower confidence limit and the A or B values of the property at room temperature to compute the A or B value at elevated temperature.

The ratio of two population means (TUS at T_1, TUS at RT) is expected to exceed the lower confidence limit, which is defined as

$$\text{Lower confidence limit} = \overline{R} - t_{0.95}\, s/\sqrt{n} \ ,$$

where $\overline{R}$ is the mean of the n ratios, and $t_{0.95}$ is the fractile of the t distribution for n-1 degrees of freedom at the 5 percent risk level. This lower confidence limit is also termed the reduced ratio and, to obtain the elevated temperature design allowables, it is multiplied by the room temperature design allowable. These computations are carried out at each temperature and the results are plotted graphically and expressed as a smooth curve, which becomes the design curve.

In this program there obviously were not sufficient data generated to comply with any of these suggestions. For example, for each alloy there were 10 values for each of two heats at each temperature. For one heat there were two coating batches and for the second heat, one coating batch which would provide three lots for the ratioing technique, if employed.

On the other hand, the requirements in MIL-HDBK-5B do not exclude the use of smaller populations than stated, provided the appropriate tabular values of k, associated with the number of samples is used.

For example, the direct computation of a design allowable based on a normal distribution is by means of

$$A \text{ value} = \overline{X} - k_A s$$
$$B \text{ value} = \overline{X} - k_B s \quad ,$$

where $\overline{X}$ is the mean value of the n observations and s again is the standard deviation and k_A and k_B are the one-sided tolerance factors corresponding to the appropriate proportion of a normal distribution (0.99 for A values, 0.90 for B values) and a confidence coefficient of 0.95. Chapter 9 contains a table of such k values for various n.

Thus, if one indeed has a population of 100 values from such a table, $A = \overline{X} - 2.684s$; whereas, if one had only 20 values, such as available from this program by combining data from two heats, $A = \overline{X} - 3.295s$. In some cases, only 10 data points (welds) and 5 data points (cyclic exposures) were available, providing k values of 3.981 and 5.741, respectively. It can be seen from the increase in k values that the smaller the sample size, the more conservative the A value might be expected to be to provide a confidence of 95 percent. Obviously, this conservatism may not be in proportion to k, since s can generally be expected to increase as the sample size increases.

This discussion is presented at this point to provide some basis for decisions made in the analysis of the data. It should be stated that the allowable strength values resulting from the analysis presently are considered as tentative design allowables. Once additional data become available from other programs in progress, their combination with the results of this program may provide a better basis for establishing firm allowables for the two systems studied.

Once again it is emphasized that, in the analysis that follows, the cross-sectional areas employed in the stress calculations are those of the uncoated substrate (average width and thickness measurements) shown in Figures 2 and 3. However, Table 14 has been prepared which shows the estimated cross sections of each group in (1) the uncoated condition, (2) in the as-coated condition, and (3) in the as-coated condition after 5, 10, and 30 cycles. These values may be used if one is interested in computing strength on the basis of residual substrate area using the tensile load information contained in Appendix B.

Sheet-to-Sheet Variability

In any one of the coating/substrate systems, the population of tensile data on the as-coated material consisted of data from two heats of base material, one of which was supplied in several sheets. Material from one of the heats was coated in two batches, whereas material from the second heat was coated in one batch.

In attempting to establish the population base for each coating/substrate system, one of the first problems was to assess the variability between sheets. The specimen allocations for the as-coated specimens in Tables 7 and 8 showed that

TABLE 14. AREA DEPLETION (SUBSTRATE CONSUMPTION) OF SPECIMENS AS A RESULT OF COATING AND T/P CYCLING

Group No.	Cross-Sectional Area of Specimens in $Inches^2$			
	Uncoated	As-Coated and After 5 T/P Cycles	After 10 T/P Cycles	After 30 T/P Cycles
1	0.00375	0.00319	0.00311	0.00304
2	0.00375	0.00321	0.00313	0.00306
3	0.00375	0.00319	0.00311	0.00304
4	0.00375	0.00324	0.00316	0.00308
5	0.00373	0.00303	0.00296	0.00288
6	0.00373	0.00297	0.00290	0.00283
7	0.00373	0.00305	0.00298	0.00290
8	0.00373	0.00310	0.00303	0.00295
9	0.00375	0.00303	0.00296	0.00288
10	0.00375	0.00303	0.00296	0.00288
11	0.00375	0.00303	0.00296	0.00288
12	0.00375	0.00303	0.00296	0.00288
13	0.00375	0.00317	0.00309	0.00302
14	0.00375	0.00317	0.00309	0.00302
15	0.00370	0.00283	0.00276	0.00269
16	0.00370	0.00283	0.00276	0.00269
18	0.00373	0.00320	0.00313	0.00307
19	0.00373	0.00333	0.00326	0.00319
20	0.00373	0.00336	0.00329	0.00322
21	0.00373	0.00328	0.00321	0.00315
22	0.00373	0.00313	0.00306	0.00300
23	0.00373	0.00318	0.00311	0.00305
24	0.00375	0.00332	0.00325	0.00318
25	0.00375	0.00321	0.00314	0.00308
26	0.00348	0.00313	0.00306	0.00300
27	0.00348	0.00305	0.00299	0.00292

for each heat supplied in more than one sheet there were only a few specimens per sheet tested at RT, 1000 F, 2000 F, and 2400 F, so that a detailed analysis was not possible. In fact, of the two sheets of VH109/C129Y, allocated to as-coated, base-material specimens, each sheet was processed with a different coating batch. Consequently, the data for R512E/Cb752 were the only data that could be examined qualitatively at selected test temperatures to determine whether the tensile properties were ordered by sheet number. The results of the limited evaluation conducted showed that no one sheet had consistently higher or lower properties than any of the others. Thus, the data within a heat from the various sheets and for the two batch coatings (at least for R512E/Cb752) appeared to be homogeneous on a qualitative basis.

Coating-Batch Variability

The next step in the analysis was to test whether results from the two coating batches within a given heat could be combined. The analysis was done only on data taken at room temperature for both R512E/Cb752 and VH109/C129Y.

The computational scheme first employed the F test to determine whether the standard deviations were homogeneous. If they were, the t test was employed to determine whether the means were homogeneous. The specific details of these two tests are described in statistical analysis texts, as well as in Chapter 9 of MIL-HDBK-5B. The procedure at BCL involved the use of a computer program, SEVRAL, briefly described below.

Program SEVRAL is a computer routine that tests the homogeneity of variances (s^2, standard deviation squared) that have been computed for a number of subpopulations within a larger population of values. The question of homogeneity of variances has to be decided first, since the subsequent test for homogeneity of the means is based on the assumption that the standard deviations are homogeneous.

The input for SEVRAL are the sample statistics for each subpopulation: the number of tests, the average value, and the standard deviation. With these input data, SEVRAL performs the Bartlett test for the variances, which, for two subpopulations as in this program, is the F test.

The computation results in a calculated Chi-squared value that is compared with a tabular value (stored in the computer) for a significance level $\alpha = 0.05$. If the calculated value is smaller than the tabulated value, the conclusion is that the standard deviations of the group of variances are all from the same population.

At this point, the program pools the standard deviations and begins the test for homogeneity of the means. In this computation, a value Q (also at a significance level $\alpha = 0.05$) is computed and is compared as before with a tabular value. Once again, the comparison of the computed value with the tabular value is made, so that a lower calculated value indicates that the means also are homogeneous at a 95 percent confidence level.

Based on the input data from the room-temperature tests in Table 15, an example of the output from SEVRAL is shown in Tables 16 and 17. This calculation examines whether data for each heat that involved two coating batches could be combined, i.e., Heat 770022 for Cb752 and Heat 572038 for C129Y.

TABLE 15. SUMMARY OF STATISTICS ON TENSILE PROPERTIES (BASED ON ORIGINAL SPECIMEN DIMENSIONS) OF AS-COATED MATERIAL AT ROOM TEMPERATURE

Subgroup	Coating/Alloy	Heat No.	Coating Batch No.	TYS n	TYS $\bar{x}$	TYS s	TUS n	TUS $\bar{x}$	TUS s	e[(a)] n	e[(a)] $\bar{x}$
1	R512E/Cb752	770022	1	6	53.25	1.107	6	66.84	1.106	6	18.6
2	Ditto	770022	2	4	53.88	0.670	4	68.14	0.463	4	18.6
3	VH109/C129Y	572038	1	5	62.70	1.484	5	77.70	2.032	5	17.4
4	Ditto	572038	2	5	60.72	1.112	5	74.48	1.510	5	18.2

(a) A logarithmic transformation of elongation values was made before computing average and standard deviation.

In each printout (Tables 16 and 17), the first two lines below the column headings are the descriptive information and sample statistics taken from Table 15 for TYS and TUS. These are followed by nine entries which summarize various stages in the calculation.

Next is shown the Chi-squared value that is compared with the tabular value. In Table 16, the computed Chi-squared values for TYS and TUS are less than the tabular value and one concludes that the variances are "equal".

The final three lines present successively the computed Q values, the corresponding tabular values, and the conclusion that, in this case, the means are "equal".

Thus, from SEVRAL and Table 16 one concludes for R512E/Cb752 that at room temperature the tensile data from the two coating batches of Heat 770022 can be combined with 95 percent confidence.

A similar printout in Table 17 indicates that for VH109/C129Y the data for the two coating batches cannot be combined, since in the Q test at the 95 percent confidence level, the computed value was higher than the tabular value.

Heat-to-Heat Variations

In the previous section it was shown that data for two coating batches of the R512E/Cb752 system probably could be combined into one population and that

TABLE 16. ANALYSIS OF BATCH-TO-BATCH COATING VARIATION IN R512E/Cb752

IDENTIFICATION	TYS, KSI NUMBER	TYS, KSI AVERAGE	TYS, KSI STD.DEV.	TUS, KSI NUMBER	TUS, KSI AVERAGE	TUS, KSI STD.DEV.
R512E/CB752 HT.770022 BATCH 1	6	53.25	1.1070	6	66.84	1.1060
R512E/CB752 HT.770022 BATCH 2	4	53.88	0.6700	4	68.14	0.4630
T = NUMBER OF ITEMS IN GROUP		2.			2.	
DF = NUMBER OF DEGREES OF FREEDOM		8.			8.	
N = HARMONIC MEAN OF N		4.80			4.80	
DX = MAXIMUM DIFFERENCE IN AVERAGES		0.63			1.30	
WV = WEIGHTED VARIANCE		0.9342			0.8449	
WSD = WEIGHTED STANDARD DEVIATION		0.9666			0.9192	
X1 = DF X LOG10(WV)		-0.2363			-0.5855	
X2 = SUM OF (DFI X LOG10(VI))		-0.6021			-1.5690	
C = BARTLETT #C#		1.2042			1.2042	
CHI SQUARED = 2.3026/C X (X1-X2) =		0.6994			1.8805	
TABULAR VALUE FOR ALPHA =.05, T-1=1		3.84			3.84	
THEREFORE CONCLUDE VARIANCES ARE		EQUAL			EQUAL	
Q(1-ALPHA) = DX/WSD X SQRT(N) =		1.4280			3.0986	
TABULAR VALUE FOR ALPHA =.05, T, DF = 2, 8		3.26			3.26	
THEREFORE CONCLUDE AVERAGES ARE		EQUAL			EQUAL	

TABLE 17. ANALYSIS OF BATCH-TO-BATCH COATING VARIATION IN VH109/C129Y

IDENTIFICATION	TYS, KSI NUMBER	TYS, KSI AVERAGE	TYS, KSI STD.DEV.	TUS, KSI NUMBER	TUS, KSI AVERAGE	TUS, KSI STD.DEV.
VH109/C129Y HT.572038 BATCH 1	5	62.70	1.4840	5	77.70	2.0320
VH109/C129Y HT.572038 BATCH 2	5	60.72	1.1120	5	74.48	1.5100
T = NUMBER OF ITEMS IN GROUP		2.			2.	
DF = NUMBER OF DEGREES OF FREEDOM		8.			8.	
N = HARMONIC MEAN OF N		5.00			5.00	
DX = MAXIMUM DIFFERENCE IN AVERAGES		1.98			3.22	
WV = WEIGHTED VARIANCE		1.7194			3.2046	
WSD = WEIGHTED STANDARD DEVIATION		1.3113			1.7901	
X1 = DF X LOG10(WV)		1.8830			4.0461	
X2 = SUM OF (DFI X LOG10(VI))		1.7403			3.8952	
C = BARTLETT #C#		1.1875			1.1875	
CHI SQUARED = 2.3026/C X (X1-X2) =		0.2767			0.2927	
TABULAR VALUE FOR ALPHA =.05, T-1=1		3.84			3.84	
THEREFORE CONCLUDE VARIANCES ARE		EQUAL			EQUAL	
Q(1-ALPHA) = DX/WSD X SQRT(N) =		3.3765			4.0221	
TABULAR VALUE FOR ALPHA =.05, T, DF = 2, 8		3.26			3.26	
THEREFORE CONCLUDE AVERAGES ARE		UNEQUAL			UNEQUAL	

similar data on the VH109/C129Y system probably could not be combined. There is some uncertainty whether similar analysis of batch-to-batch variation would yield the same results at the other two temperatures (i.e., 2000 F and 2400 F) where specimen allocation permitted such a comparison. In view of the small number of specimens involved, it was considered that such additional calculations would not be too informative. Despite the negative result for the latter system, a complete analysis of the tensile data was made at each temperature to determine whether or not there was a significant heat-to-heat variation or whether from statistical inferences the data could be combined. The implied assumption is that batch-to-batch (or sheet-to-sheet) differences for VH109/C129Y can be ignored.

The method of calculation again involved the computer program SEVRAL. The input data for each temperature and material/coating system roughly included

Heat A, Coating Batch 1, five specimens
Heat A, Coating Batch 2, five specimens
Heat B, Coating Batch 2, ten specimens.

Minor variations in the actual quantities of specimens employed were experienced because of the allocation procedures and, as pointed out in a subsequent section, because some specimens were eliminated because of atypical behavior.

Under each coating system/material combination the sample statistics $\overline{X}$ and s are summarized in Table 18. The first heat listed comprises data from several sheets and two coating batches and the second heat, data from one sheet and one coating batch. In the "Test Answer" columns, derived by Program SEVRAL, the letter U indicates that at the 95 percent confidence level one <u>cannot</u> conclude that the indicated differences in $\overline{X}$ and s from the two heats is by chance alone (more directly, a heat-to-heat difference is suggested). The letter E indicates that at the 95 percent confidence level one <u>can</u> conclude that the indicated differences in $\overline{X}$ and s from the two heats is by chance alone (or more directly if both s and $\overline{X}$ show E's, that <u>no</u> heat-to-heat difference is suggested).

The order of computation, it is remembered, is first to test the variances (s^2). Examination of the Test Answer column for s for R512E/Cb752 shows that in 14 out of 16 cases (for yield and ultimate), the standard deviations at each temperature can be pooled in order to test the means. The Test Answer column for $\overline{X}$ for the same system shows that at all temperatures, there is a heat-to-heat variation in yield and ultimate strength values. Essentially, the same conclusion results from the analysis of VH109/C129Y. A further point of interest is that there was no predominant difference in variances among samples representing only one sheet and one coating batch and those representing several sheets and two coating batches. This is considered rather strong evidence that there is no significant sheet-to-sheet nor batch-to-batch variation for either material system.

It is at this point in analysis that the reality of the task and the strict adherence to statistical inferences diverge and engineering judgment takes over.

TABLE 18. RESULTS OF ANALYSIS OF HEAT-TO-HEAT VARIATIONS FOR COATED COLUMBIUM ALLOY SYSTEMS

	R512E/Cb752						VH109/C129Y					
	$\bar{X}$, ksi			s, ksi			$\bar{X}$, ksi			s, ksi		
Temperature, F	Heat 770022	Heat 760055	Test Answer	Heat 770022	Heat 760055	Test Answer	Heat 572038	Heat 57006	Test Answer	Heat 572038	Heat 57006	Test Answer
				Yield Strength Averages and Standard Deviations								
RT	53.51	55.55	U	0.9670	0.9410	E	61.71	64.61	U	1.6180	0.8050	E
1000	31.25	32.48	U	0.9100	1.2230	E	37.06	38.33	U	1.0110	0.4530	E
1300	29.60	31.23	U	0.9150	0.3190	U	35.37	35.81	E	1.0890	0.7350	E
1600	29.78	33.15	U	0.8870	1.2180	E	34.70	36.48	U	1.3910	0.4850	U
1800	30.28	32.32	U	1.3780	1.1630	E	34.27	36.32	U	0.6810	0.6630	E
2000	29.85	33.24	U	0.8230	0.5970	E	34.12	35.73	U	1.3140	0.7650	E
2200	25.81	29.76	U	0.6740	0.3380	E	32.31	33.33	U	1.0640	0.6290	E
2400	24.77	27.41	U	0.6540	1.3760	U	28.48	29.21	U	0.7210	0.5500	E
				Ultimate Strength Averages and Standard Deviations								
RT	67.36	72.80	U	1.0940	0.9230	E	76.09	78.43	U	2.3900	1.0400	U
1000	39.63	42.37	U	2.0670	1.4020	E	53.70	54.93	E	1.1840	0.8700	E
1300	34.77	37.17	U	1.2960	0.7240	E	39.52	41.60	U	1.4820	0.9910	E
1600	30.85	33.73	U	1.0010	1.4660	E	36.20	38.05	U	1.8870	0.5910	U
1800	31.32	34.03	U	1.3620	0.9340	E	36.30	30.43	U	0.5080	1.0910	U
2000	31.43	34.13	U	1.0850	1.2120	E	37.99	39.81	U	1.8270	0.9900	E
2200	30.32	35.92	U	0.7940	0.5770	E	37.30	38.51	U	1.2440	0.9090	E
2400	27.47	31.44	U	1.0550	1.6110	E	31.23	32.39	U	1.1860	0.9630	E

The reality of the task is that at this point in time it would be desirable to have available a moderately conservative estimate of the probable A and B design allowables for these two systems over the temperature range of interest. Then as the data pool increased with time, based on essentially similar material processing, the results from other heats can be added. At some stage, sufficient data will be available through quality-control data to characterize the distribution of heat averages and finally deduce the minimum design values (A and B basis) with more rigor.

Examination of the heat averages at each temperature in Table 18 shows that the difference in $\bar{X}$ from one heat to the other for both systems usually is about 3 ksi. Some values are higher--up to 5.4 ksi; some are lower--less than 1 ksi. The differences tend to be significantly larger for R512E/Cb752 than for VH109/C129Y, which is believed to be only a fortuitous situation (in heat selection), since there was much larger scatter in coating thickness for the latter system, as previously discussed.

Now if the s values in Table 18 also are examined, two features emerge that are important to consider. First, one might expect s to increase with increasing temperature; however, the trend in s is that it is reasonably constant over the temperature range. Second, when one focuses on the heat for each system for which there were several sheets and two coating batches, the R512E/Cb752 system has somewhat lower average s values than does VH109/C129Y, again as one might expect, based on the coating measurements. Specifically, these averages are as follows:

Alloy/Coating System	Property	Average s, ksi
R512E/Cb752	TYS	0.9
	TUS	1.2
VH109/C129Y	TYS	1.1
	TUS	1.5

Now if one assumes from experience that the addition of data from many heats will raise the s value somewhat, the following s values might be realistic estimates for the two material systems:

Alloy/Coating System	Property	Estimated Average s Value, ksi
R512E/Cb752	TYS	1.2
	TUS	1.6
VH109/C129Y	TYS	1.4
	TUS	2.0

With such s values, and based on the statistics associated with an assumed data pool of 100 such heats or process combinations (heat and coating batch), the range in tensile strength that would contain 98 percent of the 100 sets of data would be about 8 ksi for R512E/Cb752 and 11 ksi for VH109/C129Y. For yield strength, comparable values are 6 ksi and 8 ksi, respectively. As noted in Table 18, all of the differences in the heat averages are well within these ranges.

Another index of expected performance is the coefficient of variation which is the simple ratio of $s/\overline{X}$. A recent computation of $s/\overline{X}$ from large volumes of data* for 7075-T6 sheet aluminum alloy, Ti-6Al-4V annealed plate, and 300 M steel at the 280 ksi strength level showed $s/\overline{X}$ to be as follows for tensile yield strength:

Alloy	Coefficient of Variation
7075-T6 sheet	0.023
Ti-6Al-4V plate	0.046
300 M steel forgings	0.023

* From the MIL-HDBK-5 files at BCL.

Again an examination of all of the s and $\overline{X}$ values in Table 18 shows that the range in $s/\overline{X}$ is approximately 0.02 to 0.05, which suggests that the data on these coating/material systems are in the same range for other alloys. Both this observation and the one above relative to the range of expected average values for various heats suggest that at this point in time a realistic expedient to evolve tentative design allowables for these two systems is to pool the data at each temperature, assume a normal distribution, and compute A and B values. This set of computations is carried out and discussed in the next section.

Computation of Tentative Design Allowables for As-Coated Columbium Alloys

The computation of A and B values was accomplished using one of the computer programs employed on the MIL-HDBK-5 program. The input data were the tensile properties, TUS, TYS, and e. The program automatically computed $\overline{X}$ and s for a set of data, and determined whether the distribution was normal or not. If the distribution was not normal, A and B values could not be automatically computed since with this set of data there were not enough data at any temperature to permit the use of the nonparametric analysis contained in the computer program. In those nonnormal cases, the distribution was assumed normal and the computations were made with a desk calculator. In the computer program the elongation values are expected to be log normal*, hence the elongation values were transformed in the computer to $\log_{10}$ values prior to the A and B value computations. If the data were log normally distributed, the computer automatically computed and printed out $\overline{X}$, and s on a $\log_{10}$ basis and the A and B values were computed on the same basis but converted back to elongation in percent. Once again, when the computer program indicated that the $\log_{10}$ distribution was not normally distributed, the assumption of normality was made and the A value computations were accomplished with a desk calculator.

It should be noted that the procedure in MIL-HDBK-5 is to compute A and B values for F_{tu} and F_{ty}, but only A values for e.

The summaries of these calculations are presented in Table 19 for R512E/Cb752 and in Table 20 for VH109/C129Y. Note in both of these tables that A and B values are given for as-coated material, as-coated welded material, and as-coated material with 5-, 10- or 30-T/P cycles prior to tensile testing. In each case, the computations are based on the exact population of values from the test data. Appendix C shows the basic data employed and the specific printout from the computer for each test condition.

In each of these tables, there are a number of values in parentheses. These are the A and B values that had to be computed with a desk calculator because the computer program indicated the combined population was not normally distributed. Predominantly, these represented elongation values which are often not normally distributed even after the logarithmic transformation, especially when the absolute value is close to 0 percent elongation.

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* Experience has shown that elongation values for a material are more nearly normal after a $\log_{10}$ transformation.

TABLE 19. R512E/Cb752 DESIGN ALLOWABLES COMPUTATION SUMMARY BASED ON COMBINED HEATS

	RT		1000		1300		1600		1800		2000		2200		2400	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
As Coated																
F_{tu}	60.3	64.4	33.3	36.4	30.7	32.9	25.9	28.5	26.7	29.1	26.9	29.3	(23.4)	(27.4)	21.4	24.8
F_{ty}	49.9	51.8	27.8	29.4	(26.9)	(28.3)	24.8	27.5	25.9	28.1	(25.2)	(27.8)	(20.9)	(23.7)	20.4	22.8
e	(12.6)		(2.7)		(0.5)		(0.8)		(0.3)		(1.3)		(1.8)		(1.4)	
Welded																
F_{tu}	61.5	62.6	(37.0)	(38.9)	32.2	33.2	(27.7)	(28.8)	25.8	27.4	(27.7)	(28.7)	27.9	28.7	24.4	25.5
F_{ty}	47.3	48.5	25.9	27.7	(28.0)	(28.5)	26.7	27.7	26.8	28.0	25.6	27.1	24.0	25.1	20.0	21.6
e	7.0		1.7		(0.5)		(1.0)		(0.1)		(0.4)		0.7		0.4	
5 T/P Cycled																
F_{tu}	59.7	62.2	(34.6)	(37.2)	27.5	30.3	24.5	27.2	28.5	29.5	27.4	29.1	24.1	26.1	24.1	25.4
F_{ty}	51.5	53.5	28.7	29.9	26.1	28.4	26.6	28.1	26.1	27.2	(25.0)	(26.8)	22.3	24.1	21.2	23.1
e	9.5		2.2		(0.1)		(0.2)		0.8		0.4		1.0		0.7	
10 T/P Cycled																
F_{tu}	63.6	64.6	35.1	37.3	26.0	28.8	24.3	27.0	26.7	28.3	28.2	29.2	27.6	28.5	24.9	25.6
F_{ty}	53.4	54.6	28.9	30.0	25.5	27.7	23.6	26.4	25.1	27.0	27.4	28.3	25.1	26.1	(21.9)	(22.8)
e	(12.9)		(0.4)		(0.7)		0.2		0.4		(0.6)		1.5		0.7	
30 T/P Cycled																
F_{tu}	48.3	53.7	--	--	--	--	--	--	--	--	(22.2)	(25.3)	18.1	23.2	19.5	22.6
F_{ty}	46.6	49.4	--	--	--	--	--	--	--	--	(23.8)	(25.8)	18.7	22.7	18.5	21.6
e	(0.3)	--	--	--	--	--	--	--	--	--	(0.1)		(0.2)		(0.7)	

TABLE 20. VH109/C129Y DESIGN ALLOWABLES COMPUTATION SUMMARY BASED ON COMBINED HEATS

	RT		1000		1300		1600		1800		2000		2200		2400	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
As Coated																
F_{tu}	70.1	73.1	49.3	51.3	35.2	37.4	31.6	33.9	32.8	34.7	33.0	35.4	33.8	35.5	27.7	29.4
F_{ty}	56.8	59.4	33.4	35.0	32.5	33.8	(31.1)	(32.9)	31.2	32.9	30.3	32.2	29.5	30.9	26.4	27.4
e	(13.7)		(4.1)		(1.6)		(1.0)		(0.4)		(0.4)		(2.0)		(0.9)	
Welded																
F_{tu}	(62.3)	(66.3)	(44.6)	(47.5)	31.8	36.5	(27.9)	(31.6)	32.7	34.3	31.4	33.8	29.4	32.4	25.6	27.4
F_{ty}	51.1	55.0	31.8	33.7	22.9	28.0	26.1	30.0	31.9	33.4	30.3	32.3	28.9	30.9	24.5	26.0
e	(3.2)		(4.0)		0.9		(1.7)		(0.4)		(0.2)		(0.1)		(0.7)	
5 T/P Cycled																
F_{tu}	65.8	69.0	43.9	47.5	31.2	35.2	30.0	33.1	33.2	35.0	(30.5)	(33.7)	29.4	31.5	22.6	25.3
F_{ty}	54.5	56.9	33.7	35.5	(28.8)	(31.6)	29.3	31.7	30.8	32.5	28.7	31.4	29.4	30.2	21.7	23.9
e	10.3		(3.3)		(1.2)		(0.3)		(0.2)		1.0		1.1		0.7	
10 T/P Cycled																
F_{tu}	56.0	63.4	37.1	43.2	25.1	32.1	26.1	30.4	27.4	30:7	29.7	32.4	27.7	30.3	24.1	26.0
F_{ty}	47.6	53.1	28.2	32.0	30.5	33.4	25.9	29.7	29.2	31.0	29.7	31.5	(18.2)	(23.2)	21.2	23.4
e	(12.5)		(3.9)		(0.1)		(0.1)		(0.2)		0.8		0.6		0.7	
30 T/P Cycled																
F_{tu}	41.5	53.7	43.4	47.2	--	--	--	--	33.9	35.3	25.1	29.4	(28.2)	(29.4)	23.5	26.4
F_{ty}	28.6	40.0	(33.9)	(35.7)	--	--	--	--	30.0	31.6	24.1	27.2	22.3	24.5	22.0	25.0
e	8.1	--	0.4	--	--	--	--	--	0.6	--	0.8	--	0.7	--	0.2	--

It is evident from these tables that both alloys were brittle in the temperature range 1300 to 2000 F, as suggested by other data in the literature. Above 2000 F, a slight increase in ductility was observed as expected. This trough in the elongation/temperature relation also manifests itself in another way. Examination of the tables shows that yield and ultimate design strengths are nearly the same in this temperature range (1300 - 2000 F), and in some cases, it is seen that the yield strength value is higher than the ultimate strength value (for example, R512E/Cb752 welded at 1800, 5 T/P cycled at 1600; VH109/C129Y 5 T/P cycled at 2200 F, and 10 T/P cycled at 1300 F and 1800 F).

In this intermediate temperature range it is known from other studies that coated columbium alloys when tensile tested at the usual strain rates in air exhibit low values of tensile elongation[16]. This behavior is mildly sensitive to coating/substrate composition and geometry, and very sensitive to strain rate and environment. Stress-oxidation processes are believed to be responsible. The ductility minimum occurs at about 1700 F and tensile elongation may decrease to less than 1 percent. However, ductility remains sufficiently high that yield strength is not affected.

The results from this program, as shown by the design allowables calculations in Tables 19 and 20, are consistent with prior findings relative to intermediate temperature ductility minimums in coated columbium. In tests at 1600 and 1800 F, elongations ranged from essentially zero to about 4 percent. At the lower limit, very little strain hardening occurred, and ultimate tensile strengths were very close to the values for yield strength. At the higher elongation values, the strain hardening that resulted gave ultimate strength values substantially greater than the yield strengths. Depending upon the dispersion among elongation values (hence ultimate strength) within a given analysis lot, the standard deviation of ultimate strength was greater than that for the yield strength. This, coupled with a generally small amount of strain hardening, occasionally resulted in design allowable ultimate strengths that were lower than the design allowable yield strength as previously stated.

As a consequence of this behavior, it is concluded that, as a design parameter, ultimate strength is appreciably less predictable than is yield strength of coated columbium alloys at intermediate temperatures (e.g., from about 1350 to 1850 F). Accordingly, it is recommended that at temperatures between 1300 and 2000 F, the ultimate load design allowable should be based upon yield strength rather than ultimate strength.

It is further advised that caution be exercised in cases where the structural design rationale allows for stress relaxation via substantial local plastic deformation (i.e., as in "shakedown" of a structure). Whereas such a philosophy would be acceptable for many metals and alloys, it may contain serious pitfalls in the 1600 to 1800 F temperature regime in the case of coated-columbium alloys.

The second step in establishing the elevated-temperature design allowables consisted of a graphical examination of the results shown in Tables 19 and 20. The specific course of the analysis is subsequently described; however, it follows procedures documented in MIL-HDBK-5. These essentially consist of plotting the individually computed A values as a function of temperature, and drawing a smooth curve through the data points. For those temperature regions where metallurgical phenomena occurred (such as dynamic strain aging) that resulted in apparent strengthening, the curve was drawn nearly horizontally (essentially ignoring the strengthening. The resultant curve then was used to establish the design curve, which is a plot of strength at temperature (as a percent of room-temperature strength) versus temperature. These latter design curves are presented in a final summary section in this part of the report. In this section only the data analysis curves are shown for F_{tu}, F_{ty} and e.

Figures 13, 14, and 15 show the analysis of the information in Table 19 for R512E/Cb752 for ultimate strength, yield strength and elongation. Figures 16, 17, and 18 show a similar analysis from Table 20 for VH109/C129Y. Also plotted on each figure are the range of observed values for the two heats of material for each alloy. It is noted in Figures 13 and 16 that above 1600 F, there was some increase in ultimate strength based on the A value computations. As stated before, the effect-of-temperature curve ignored this increase and was drawn essentially horizontally, yet consistent with data above and below this range. It is also noted in these two figures that the design curve lies farther below the minimum test data than is the case for yield strength in Figures 14 and 17. This observation is related to the somewhat higher scatter in the tensile ultimate strength data as compared with that of the tensile yield strength data. In the A value computation, which accounts for probability and confidence, the greater scatter then will tend to locate the design curve for ultimate strength farther below that of the minimum test data than will be the case for the design curve for yield strength.

Figures 15 and 18 show the effect of temperature on elongation. As seen in the figures, elongation decreases from room temperature and becomes a minimum in the range 1600 to 1700 F, after which there is a slight rise in the vicinity of 2000 to 2400 F.

Comparison of the two materials shows VH109/C129Y to have tensile ultimate and yield strengths greater than those of R512E/Cb752 over the temperature range evaluated. Only minor differences exist in the A value effect of temperature curve or elongation for the two systems; however, comparison of Figures 15 and 18 show that VH109/C129Y has much greater variability in elongation than does R512E/Cb752 in the intermediate temperature range, 1000 to 1600 F. It should be noted that the tensile properties above 1600 F for both materials tended to be higher than similar properties reported in the literature. A careful evaluation of all test procedures, including temperature measurement and control, provided no reason for these differences.

Computation of Tentative Design Allowables for As-Coated Butt-Welded Columbium-Alloy Joints

Chapter 9, Section 9.4.3, of MIL-HDBK-5B describes procedures for establishing design allowables for welded joints; however, requirements as to quantities of data and heat lots are considerably more than could be obtained on this program. Consequently, in considering the data from this program, two alternatives were considered. The first involved the A and B computations

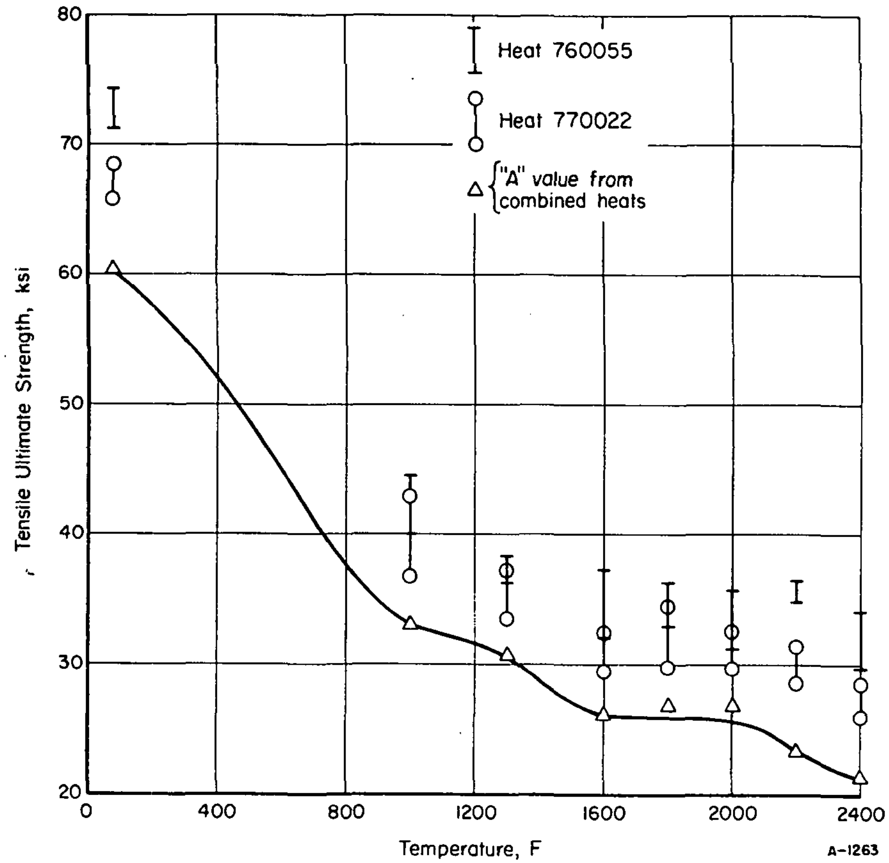


FIGURE 13. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE FOR R512E/Cb752 ALLOY (AS COATED)

Based on original substrate thickness.

(For strength values based on unreacted substrate, use 117 percent of graphical values.)

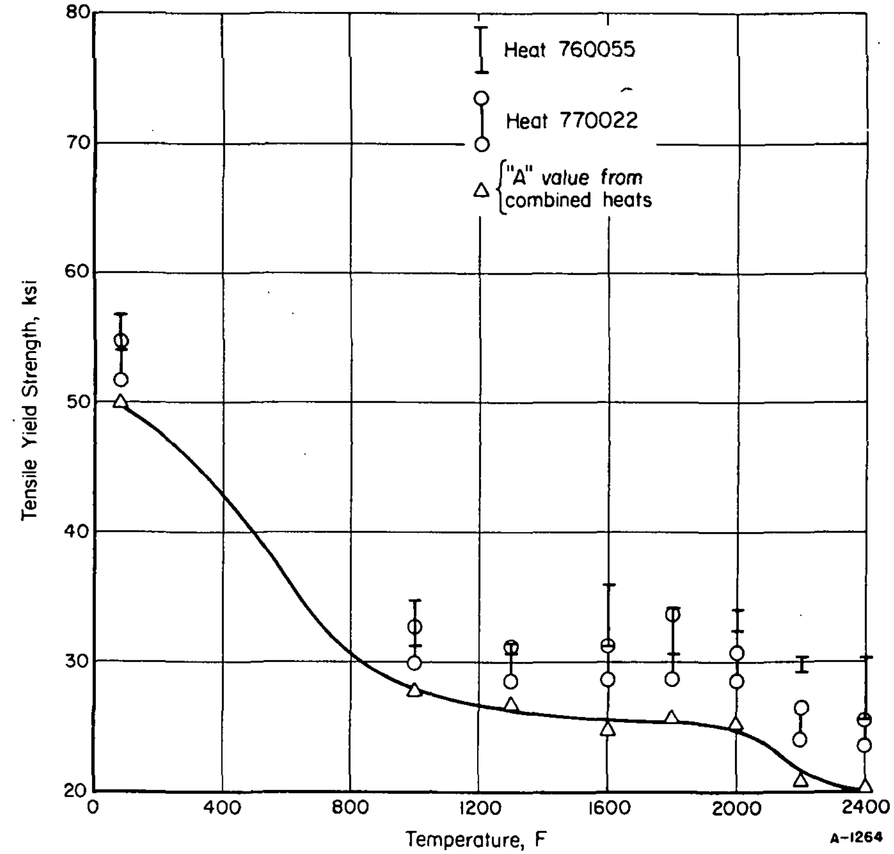


FIGURE 14. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE FOR R512E/Cb752 ALLOY (AS COATED)

Based on original substrate thickness.

(For strength values based on unreacted substrate, use 117 percent of graphical values.)

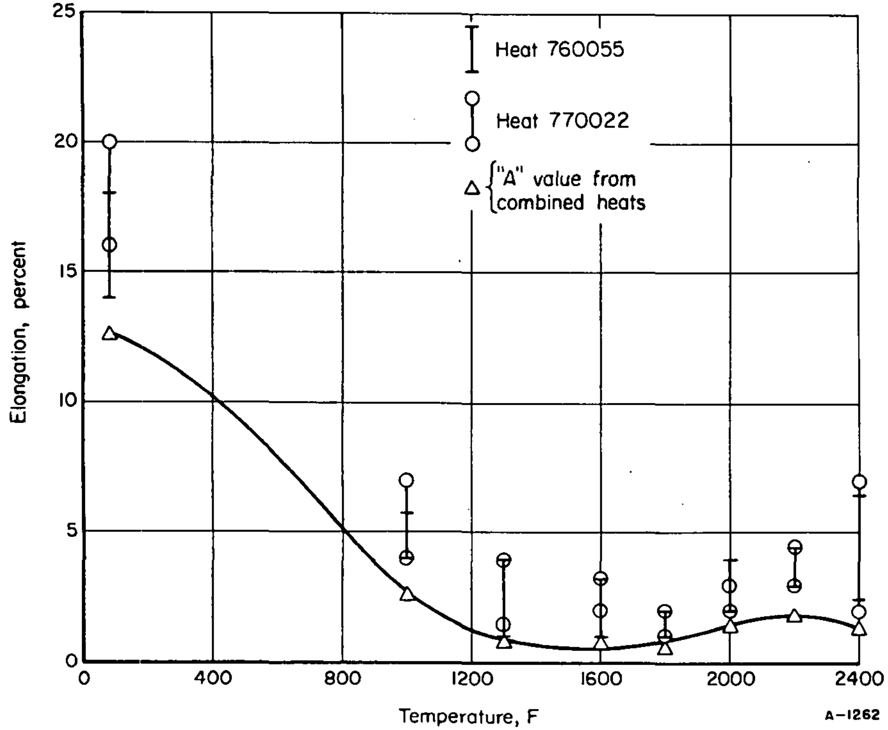


FIGURE 15. EFFECT OF TEMPERATURE ON THE ELONGATION OF R512E/Cb752 ALLOY (AS COATED)

Based on original substrate thickness.

(For strength values based on unreacted substrate, use 117 percent of graphical values.)

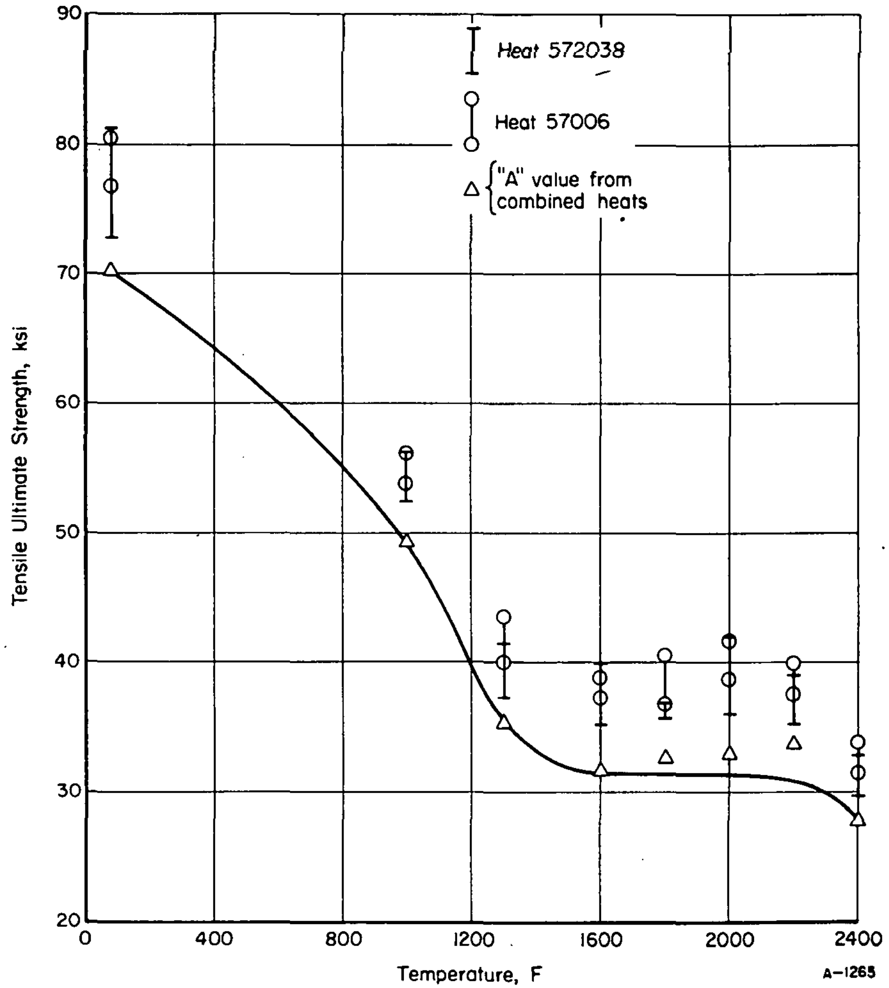


FIGURE 16. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE FOR VH109/C129Y ALLOY (AS COATED)

Based on original substrate thickness.

(For strength values based on unreacted substrate, use 117 percent of graphical values.)

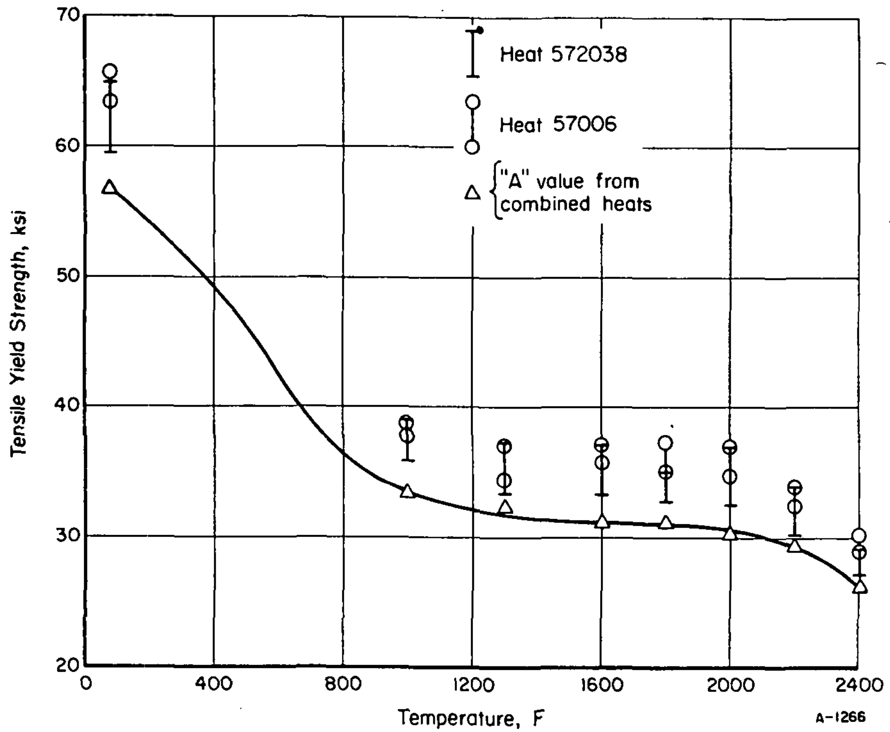


FIGURE 17. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE FOR VH109/C129Y ALLOY (AS COATED)

Based on original substrate thickness.

(For strength values based on unreached substrate, use 117 percent of graphical values.)

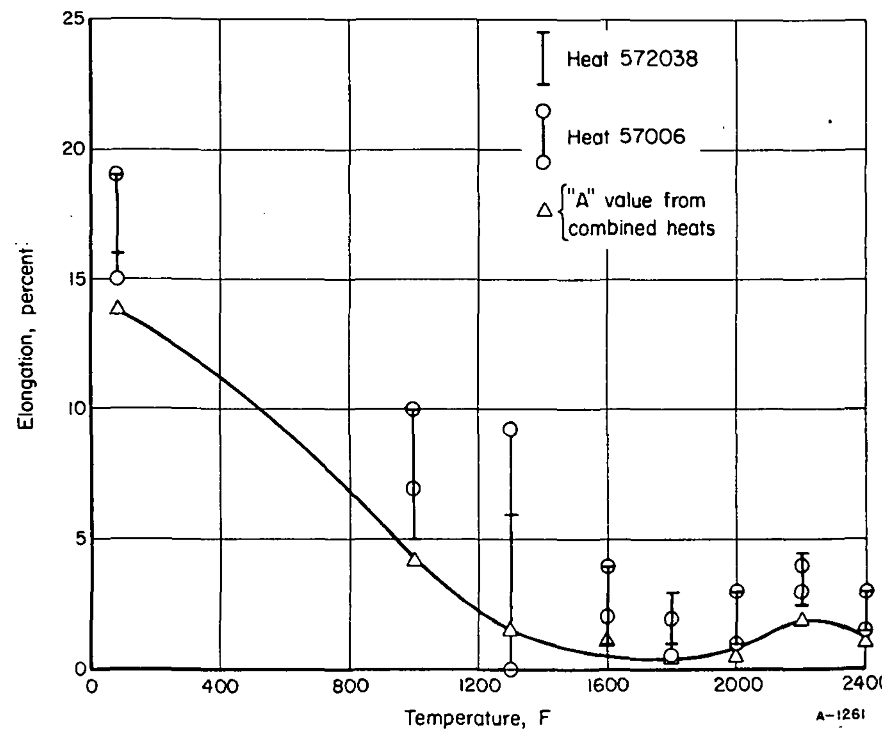


FIGURE 18. EFFECT OF TEMPERATURE ON THE ELONGATION OF VH109/C129Y ALLOY (AS COATED)

Based on original substrate thickness.

(For strength values based on unreacted substrate, use 117 percent of graphical values.)

summarized in Tables 19 and 20. The second involved establishment of a reduction factor or efficiency factor for the weld joints to be applied to the effect-of-temperature curves for ultimate and yield strength of the as-coated material.

Prior to presenting the analysis, a few comments on failure origin are in order. With regard to R512E/Cb752, examination of the failures showed that most of the time the cross section of failure was at least 1/8 inch from the weld center line, ranging up to about 5/8 inch. Thus, failures were in the base material. Nine of 80 samples, however, failed either in the weld (three specimens) or within 1/16 inch of the weld center line which was the predominant failure locations for VH109/C129Y specimens. These observations suggest somewhat lower weld joint properties than for the as-coated material at low and high temperatures.

Figures 19 and 20 show the tensile ultimate and yield strength A values from Table 19 plotted as a function of temperature for R512E/Cb752. Figures 21 and 22 show similar information for VH109/C129Y. On each of these graphs, in addition to the A values for the weld joints, are plotted the A values for the as-coated alloy, the range of welded joint test data, and the design curve for the as-coated material. The dashed line subsequently is discussed. Consider each figure separately.

In Figure 19 for welded R512E/Cb752, it is seen that the computed A values for the welded joints almost always lie slightly above the computed A values for as-coated material and follows the trend of the latter data. The scatter in the data are small. The results suggest that it might be reasonable to assume that the curve for the as-coated alloy should be appropriate for the welded material. However, superimposing Figure 19 on Figure 13 and comparing the range of test data for welded joints (Heat 770022) with that for the same heat on Figure 13 shows that the weld data scatter band is on the low side of (and slightly below) the band for as-coated material.

Figure 20 for tensile yield strength of welded R512E/Cb752 shows that the computed A values for welded joints in about half the cases fall below or on the computed A values for as-coated material, again with a trend similar to the design curve. Some test data fall below or close to the design curve (at room temperature and 1000 F). This suggests that a design curve for welded joints should fall below that for as-coated material for some range in temperature above room temperature. Again, superposition of Figure 20 on Figure 14 shows that the range of welded data is on the low side of the range for as-coated material, when the comparison is made only with Heat 770022.

In Figure 21 for welded VH109/C129Y, it is seen that the computed A values for welded joints always fall below the computed values for the as-coated material. Also, superposition of Figures 21 and 16 shows the range in weld test data to be on the low side or substantially below that of as-coated material, comparing only with Heat 572038, which is the heat from which all welded specimens were made. These observations suggest that a design curve for welded joints should lie below that for as-coated material for ultimate tensile strength.

In Figure 22 for tensile yield strength of VH109/C129Y, the computed A values for welded joints again fall below the computed values for the as-coated material, with the greatest divergence at 1300 F and 1600 F. The test data also

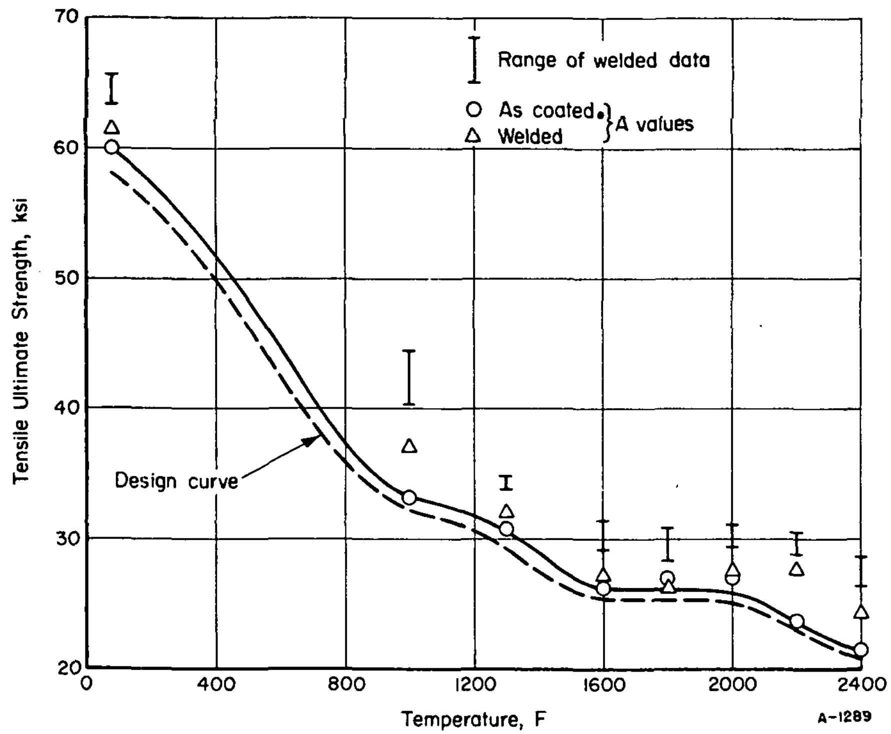


FIGURE 19. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE FOR AS-COATED BUTT-WELDED R512E/Cb752 ALLOY

Based on original substrate thickness.

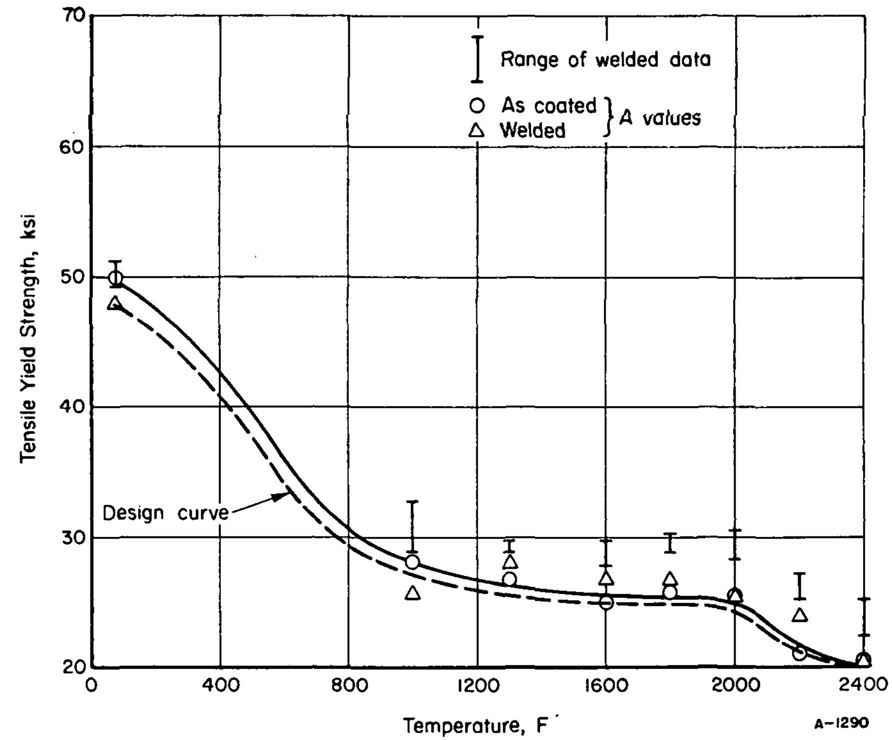


FIGURE 20. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE FOR AS-COATED BUTT-WELDED R512E/Cb752 ALLOY

Based on original substrate thickness.

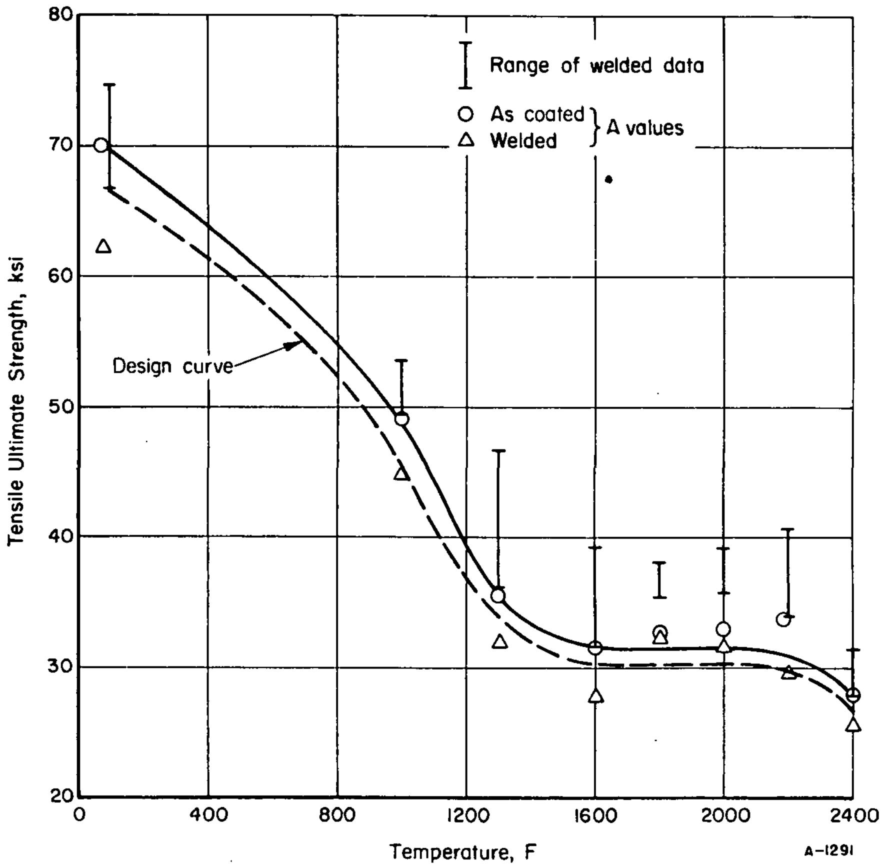


TABLE
FIGURE 21. TENSILE ULTIMATE STRENGTH AS A FUNCTION OF TEMPERATURE FOR AS-COATED BUTT-WELDED VH109/C129Y ALLOY

Based on original substrate thickness.

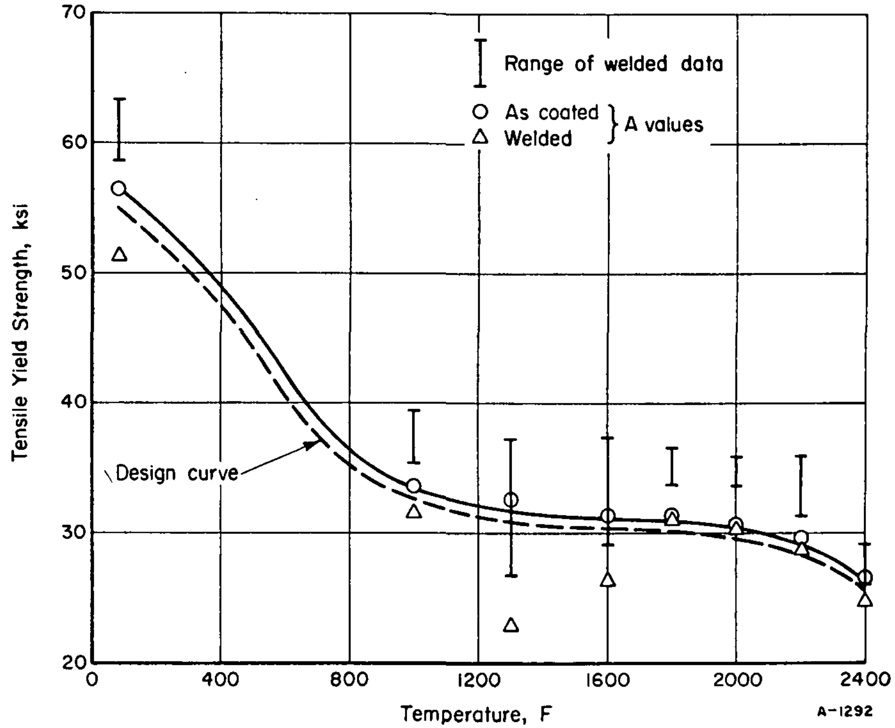


FIGURE 22. TENSILE YIELD STRENGTH AS A FUNCTION OF TEMPERATURE FOR AS-COATED BUTT-WELDED VH109/C129Y ALLOY

Based on original substrate thickness.

fall below the design curve at these temperatures. Superposition of Figures 22 and 17 shows the weld data range to be low compared with that for the same heat of as-coated material. This suggests again that the welded joint design curve should be below that of the as-coated material.

Since only ten specimens, all from one sheet and heat of material, were involved in the A value computations, it is believed that the use of the A value computations at this stage is premature. Consequently, the establishment of tentative design allowables for the welded material was considered with a more intuitive judgment procedure. Since the procedure also was used to establish the effect of the T/P cycling on design allowables, the approach is described in detail as follows.

The approach was to determine if there was some pattern in how weld efficiency varied with temperature and then make a judgment on a conservative approach to the weld design curve.

To accomplish this, the average strength for the as-coated material and welded joints was tabulated at each temperature for ultimate and yield strength, and the weld efficiency (ratio of weld strength to as-coated base-material strength) was computed. These data and computations are listed in Table 21 for R512E/Cb752 and in Table 22 for VH109/C129Y.

Examination of Table 21 shows that weld efficiency for ultimate strength for R512E/Cb752 varies from 95 to 105.5 percent, whereas that for yield strength varies from 93.5 to 103.3 percent. No clear-cut trend is evident with temperature. Consequently, it was decided to determine an average ratio for the entire range of temperature and not consider those values in excess of 100 percent. The rationale was that exclusion of values in excess of 100 percent would tend to provide somewhat more conservative values, particularly for yield strength; also, that efficiencies greater than 100 percent of base metal strength would never be used. On this basis, the average values were determined to be 97.4 percent for ultimate strength and 97.1 percent for yield strength. This is approximately the value predicted from weld geometry effects. Next, these values were compared with the individual values and the A value trends of Figures 19 and 20. On the basis of this examination, it was decided that a moderately conservative weld efficiency of 96 percent should be established for yield and ultimate strength to be applied over the temperature range RT to 2400 F for R512E/Cb752 alloy.

Examination of Table 22 shows not quite so simple a picture for VH109/C129Y. For both ultimate and yield strengths, the weld efficiencies appear to peak in the middle temperature range and taper off at low and high temperature. The same approach, however, was taken and averages for the temperature range were computed, again excluding efficiencies in excess of 100 percent. This resulted in average values of 96.4 percent for ultimate strength and 98.4 percent for yield strength. Again, these values were compared with the individual values in Table 22 and the A value trends of Figures 21 and 22. From this examination, it was decided that a moderately conservative weld efficiency of 95 percent should be established for ultimate strength and 97 percent should be established for yield strength and applied over the temperature range RT to 2400 F for VH109/C129Y alloy.

TABLE 21. COMPUTATION OF WELD EFFICIENCY FOR R512E/Cb752 ALLOY

Temperature, F	Tensile Ultimate Strength			Tensile Yield Strength		
	As Coated, ksi	Welded, ksi	Efficiency, percent	As Coated, ksi	Welded, ksi	Efficiency, percent
RT	67.36	64.29	95.3	53.51	50.09	93.5
1000	39.63	41.76	105.5	31.25	30.39	97.3
1300	34.77	34.52	99.3	29.60	29.12	98.4
1600	30.85	30.36	98.4	29.78	29.18	98.1
1800	31.32	29.74	95.0	30.28	29.69	98.2
2000	31.43	30.14	95.8	29.85	29.30	98.2
2200	30.32	29.96	98.8	25.81	26.67	103.3
2400	27.47	27.26	99.3	24.77	23.83	96.5

TABLE 22. COMPUTATION OF WELD EFFICIENCY FOR VH109/C129Y ALLOY

Temperature, F	Tensile Ultimate Strength			Tensile Yield Strength		
	As Coated, ksi	Welded, ksi	Efficiency, percent	As Coated, ksi	Welded, ksi	Efficiency, percent
RT	76.09	72.13	94.0	61.71	60.71	98.3
1000	53.70	51.67	96.1	37.06	36.49	98.5
1300	39.52	43.29	109.7	35.37	35.54	100.8
1600	36.20	36.92	101.9	34.70	35.51	102.3
1800	36.30	36.61	101.0	34.27	35.54	103.8
2000	37.99	37.31	98.0	34.12	35.20	103.2
2200	37.30	36.61	98.1	32.31	33.81	104.7
2400	31.23	29.95	96.0	28.48	28.02	98.3

As shown in Tables 21 and 22, there is a trend that the weld efficiency is lowest at the lower temperatures. As the test temperature approaches the ductile-brittle transition temperature, it would be expected that an average weld efficiency, such as used herein, could be overly optimistic.

Since the design curves in Figures 19 through 22 were based on data from both heats, the weld efficiencies would be applied to those curves on the assumption that the reduction for one heat would be similar to the reduction for another. These computations were made and the dashed curves in Figures 19 through 22 are the resultant design curves for both welded joints. Examination of Figures 19 and 20 show these curves to be conservative for R512E/Cb752, although one computed allowable at 1300 F falls below the curve.

Figures 21 and 22 show that, while many of the computed allowables fall below the curves, their present location is below all test data except for yield strength at 1300 F and 1600 F. In a subsequent section concerned with "Post-test Materials Studies", it is pointed out that the two specimens that influenced the low computed allowables are characteristic of present processing (in terms of expected range of coating thickness). However, if process controls are improved as expected for VH109 coating, the thickness variation from the process can be improved and the very low design strength attributed to excessive coating thickness or reduced substrate thickness would be minimized. As a matter of interest, had these specimens been eliminated from the data pool, the allowables points and the minimum of the range of the welded data would have been close to or higher than the as-coated base material curve. Thus, the position of the present curve appears reasonable, as do the weld efficiency factors proposed.

Determining the Effect of T/P Cycling on the Design Allowables

Statistical computations were made on the data from specimens cycled according to a simulated reentry, and the resultant A and B values are presented in Tables 19 and 20. Since only five specimens were involved for each condition tested, there is some reluctance to accept such values as statistically descriptive of the material. Accordingly, it was decided to explore the use of reduction factors as was done for the weld data.

Since the specimens for both materials came from the same heats as for the welded samples, the average strength of samples T/P cycled were compared with the average strength of the appropriate heat. The resultant reduction factor then was applied to the base material design curve.

Table 23 shows the ratios of the average strengths so computed for R512E/Cb752; Table 24, for VH109/C129Y at various test temperatures.

From Table 23, it is seen for ultimate tensile strength that the reduction factors vary without pattern with temperature--sometimes exceeding 100 percent, sometimes less than 100 percent. Thus, the decision to compute an average ratio for all temperatures was consistent with the procedure for welded

TABLE 23. COMPUTATION OF T/P CYCLING REDUCTION FACTORS FOR R512E/Cb752 ALLOY

Temperature, F	Strength Ratios for Indicated Number of T/P Cycles, percent					
	Tensile Ultimate Strength			Tensile Yield Strength		
	5	10	30	5	10	30
RT	98.0	97.9	91.4	105.6	105.2	100.0
1000	103.8	102.7	--	103.4	101.1	--
1300	98.6	94.5	--	107.0	104.4	--
1600	101.0	100.3	--	102.1	102.4	--
1800	99.4	98.1	--	95.5	98.0	--
2000	100.3	97.8	94.7	98.8	99.5	96.2
2200	95.8	97.8	100.8	103.4	107.0	110.3
2400	99.2	97.2	99.3	104.6	98.0	105.3

TABLE 24. COMPUTATION OF T/P CYCLING REDUCTION FACTORS FOR VH109/C129Y ALLOY

Temperature, F	Strength Ratios for Indicated Number of T/P Cycles, percent					
	Tensile Ultimate Strength			Tensile Yield Strength		
	5	10	30	5	10	30
RT	97.0	97.6	94.0	98.0	99.0	91.8
1000	98.3	96.8	98.4	103.1	101.2	103.3
1300	104.0	107.1	--	101.0	106.2	--
1600	104.0	101.8	--	101.8	101.9	--
1800	103.5	98.0	102.7	102.0	98.1	99.5
2000	101.0	95.5	93.8	103.6	100.3	93.1
2200	92.7	91.5	83.8	97.1	95.0	85.7
2400	94.0	91.8	98.0	95.5	93.7	103.3

material, excluding (as before) values in excess of 100 percent. For temperatures up to 1600 F, the pattern appeared to be that the yield strength of cycled material was higher than as-coated and tested material. Above 1600 F, a variable pattern existed with reduction factors sometimes greater than 100 percent. Since the predominant use is expected to be at the higher temperatures, reduction factors were computed only from the higher temperature values, ignoring values in excess of 100 percent.

In Table 24, the tendency noted with the weld ratios again appears. Thus for the middle temperature range, values in excess of 100 percent were the rule; whereas, at the low and high temperatures, values were less than 100 percent. Reduction factors were calculated on the basis of those values less than 100 percent. In these computations, the extremely low value at 2200 F and 30 T/P cycles was considered atypical and was not employed.

In both tables, several blanks appear in columns for 30 T/P cycles. It was at these temperatures that exothermic temperature rise occurred that prevented attainment of useful data.

From the averaging calculations, the following average reduction factors were obtained:

	R512E/Cb752			VH109/C129Y		
Strength	5 T/P	10 T/P	30 T/P	5 T/P	10 T/P	30 T/P
Ultimate	98.2%	97.2%	93.0%	95.5%	95.2%	96.0%
Yield	97.1%	98.5%	96.2%	98.5%	96.4%	96.9%

These values show a trend toward lower factors the greater the number of exposures, although not a consistent one. If there is an effect of T/P cycling, this would be the expected trend. Thus, the following reduction factors are suggested based on the limited results from this program:

	R512E/Cb752			VH109/C129Y		
Strength	5 T/P	10 T/P	30 T/P	5 T/P	10 T/P	30 T/P
Ultimate	97%	97%	93%	95%	95%	95%
Yield	97%	97%	95%	97%	96%	96%

These reductions are not large and are considered to apply over the entire temperature range. Some further discussion relative to the 30 T/P cycle data for R512E/Cb752 is presented in a subsequent section and suggests a further limitation to these factors in design considerations.

Modulus of Elasticity and Load-Strain Curves

Extensometers used to measure deformation in the elastic region during tensile testing of the coated-columbium alloys resulted in well-defined load-strain curves at room temperature. However, at elevated temperature load-extension curves were erratic, partly because of warping of the specimen and partly due to the tendency for the extensometer to slip. This led to difficulty in determining the elastic modulus. Pertinent values obtained from the data are reported in this section. As with all other data, modulus has been computed on the basis of the original substrate cross section prior to coating.

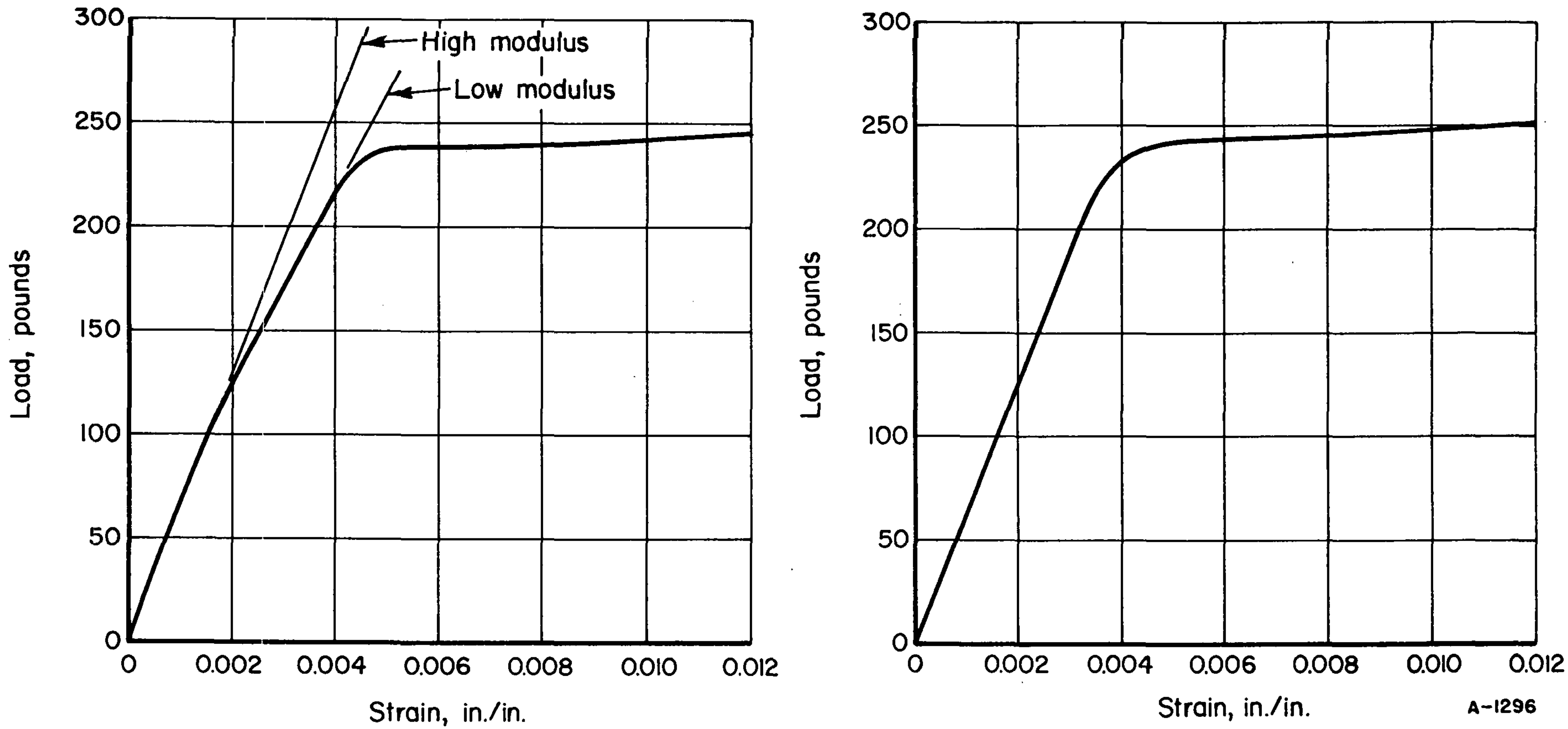
At room temperature, there were three shapes of load-strain curves observed. The two more frequently observed are reproduced from the chart traces in Figure 23. Curve (a), observed most often, contains a well-defined double modulus. The knee in the elastic portion most frequently occurred at a load in the range 40 to 60 percent of the yield load. Thus, for this curve shape it was possible to identify two modulus values. Curve (b) contained a single modulus line to load values in the range 70 to 90 percent of the yield load, followed by a gradual curve through the yield load range. The slope of the modulus line for these latter type curves most frequently was consistent with the initial modulus line of the double-modulus curve shapes. The third type of curve (infrequently observed) was very gently curved over most of the load-strain record.

Curve shapes such as (a) and (b) were observed in the room-temperature tests of as-coated, welded and coated, and thermally cycled specimens. At elevated temperature, none of the Curve (a) shapes were observed for either material. Thus, elevated-temperature modulus was obtained from load-strain curves containing a single modulus. For these curves, the elastic portion of the curve was well defined, usually in the range 20 to 70 percent of yield load. Thus, the modulus values derived from the data appear to be consistent with the high-modulus portion of the room-temperature curves.

Evaluation of the individual stress-strain curves derived from the load-strain traces provided the average modulus values shown in Table 25. Note in the table that at room temperature the low modulus (secondary) for both columbium alloys is about 83 percent of the primary modulus.

These average values are plotted on Figure 24. The figure shows that VH109/C129Y retained its high modulus over a greater range of temperature than did R512E/Cb752. However at high temperatures, it appears that the latter alloy and coating will have the higher modulus above 2400 F. These trends with temperature for tensile modulus have also been observed for the two base alloys.

Typical load-strain curves were selected from the data and are reproduced in Figures 25 and 26 to load levels somewhat beyond the yield load for R512E/Cb752 and VH109/C129Y, respectively. In the final section of this part of the report, these curves have been converted to typical stress-strain curves. In both Figures 25 and 26, the selected curves are those that provide a modulus value close to the average for that temperature. In the case of the stress-strain curves in a following section, no attempt was made to adjust the curves to provide modulus values identically equal to the average values.



(a) Primary and Secondary Modulus Curve Shape

(b) Primary Modulus Curve Shape

FIGURE 23. TYPICAL LOAD-STRAIN CURVE SHAPES AT ROOM TEMPERATURE

TABLE 25. AVERAGE MODULUS OF ELASTICITY VALUES FOR COATED COLUMBIUM ALLOYS

Temperature, F	R512E/Cb752, 10^6 psi		VH109/C129Y, 10^6 psi	
RT	15.3	High	16.3	High
	12.8	Low	13.3	Low
1000	13.8		15.7	
1300	13.0		--	
1600	12.5		15.8	
1800	12.2		14.6	
2000	11.7		13.8	
2200	10.4		10.4	
2400	9.4		10.1	

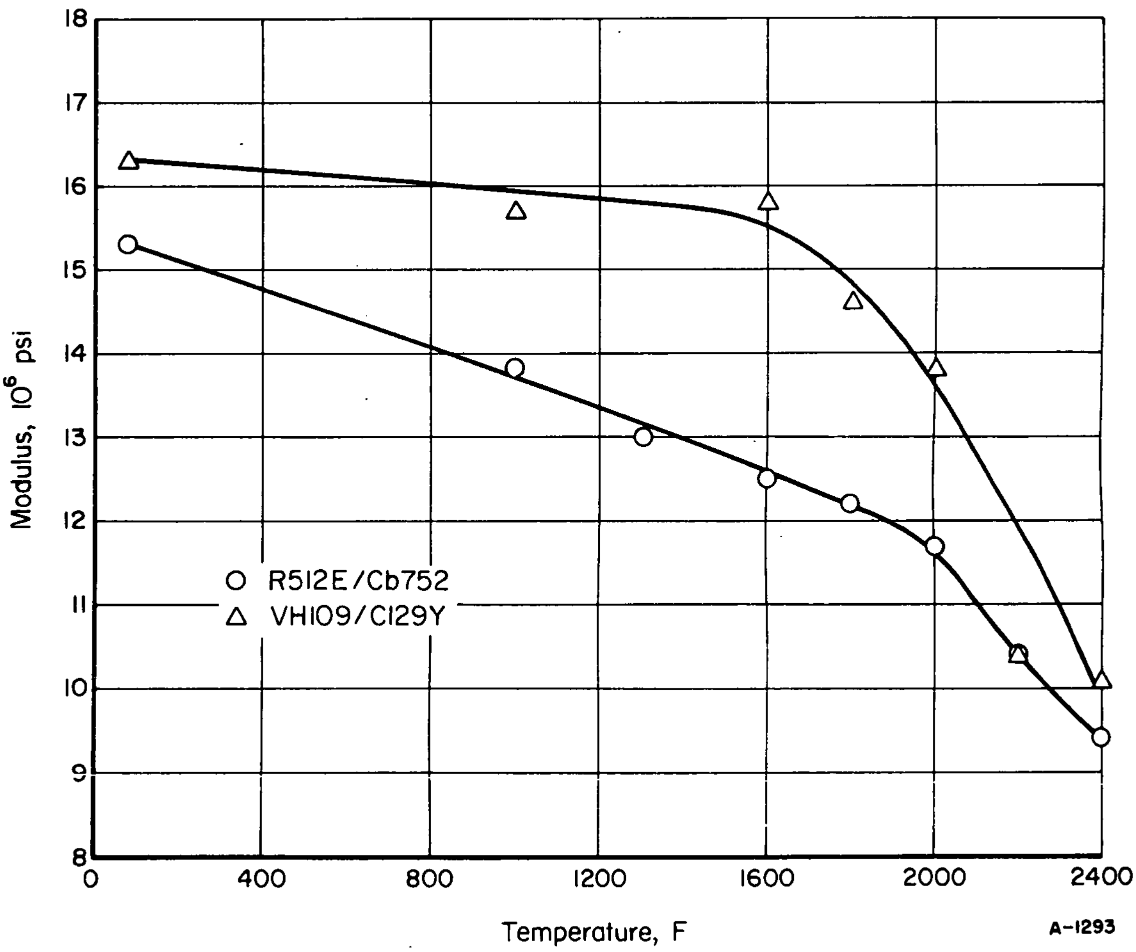


FIGURE 24. TENSILE MODULUS AS A FUNCTION OF TEMPERATURE FOR AS-COATED ALLOYS

Based on original substrate thickness.

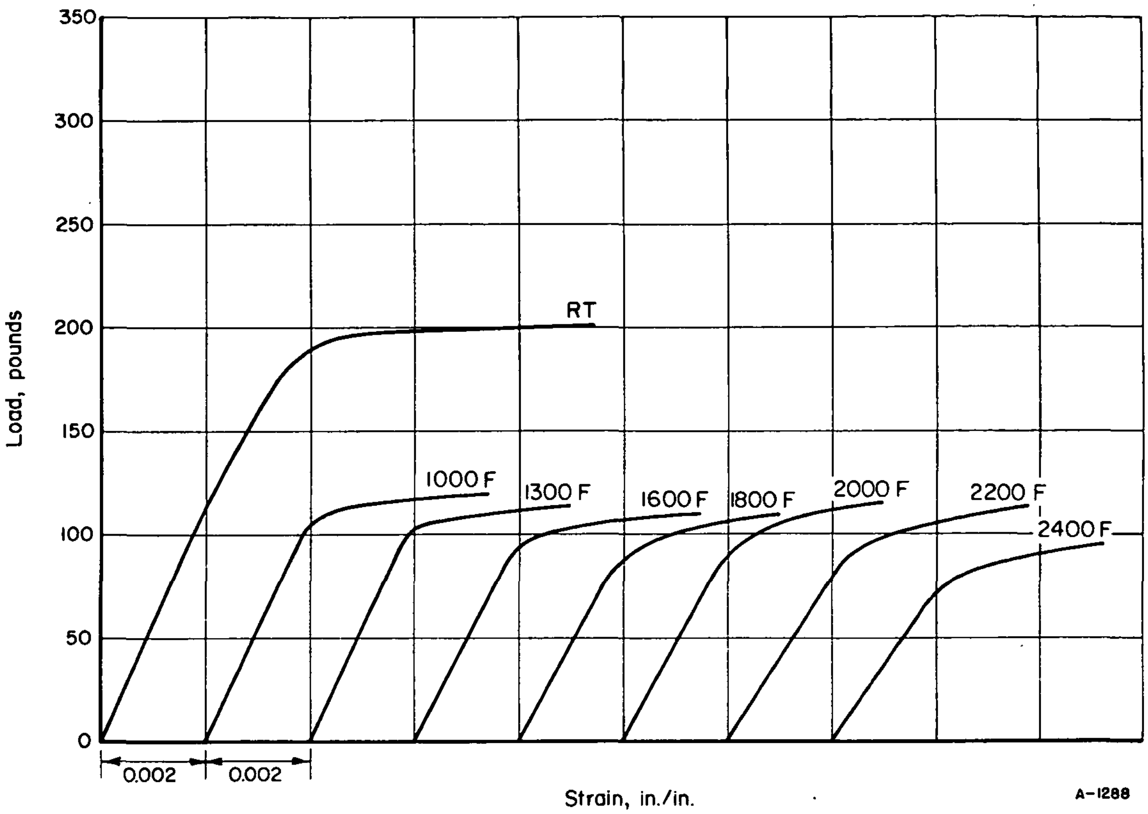


FIGURE 25. LOAD-STRAIN CURVES FOR R512E/Cb752 AT VARIOUS TEMPERATURES

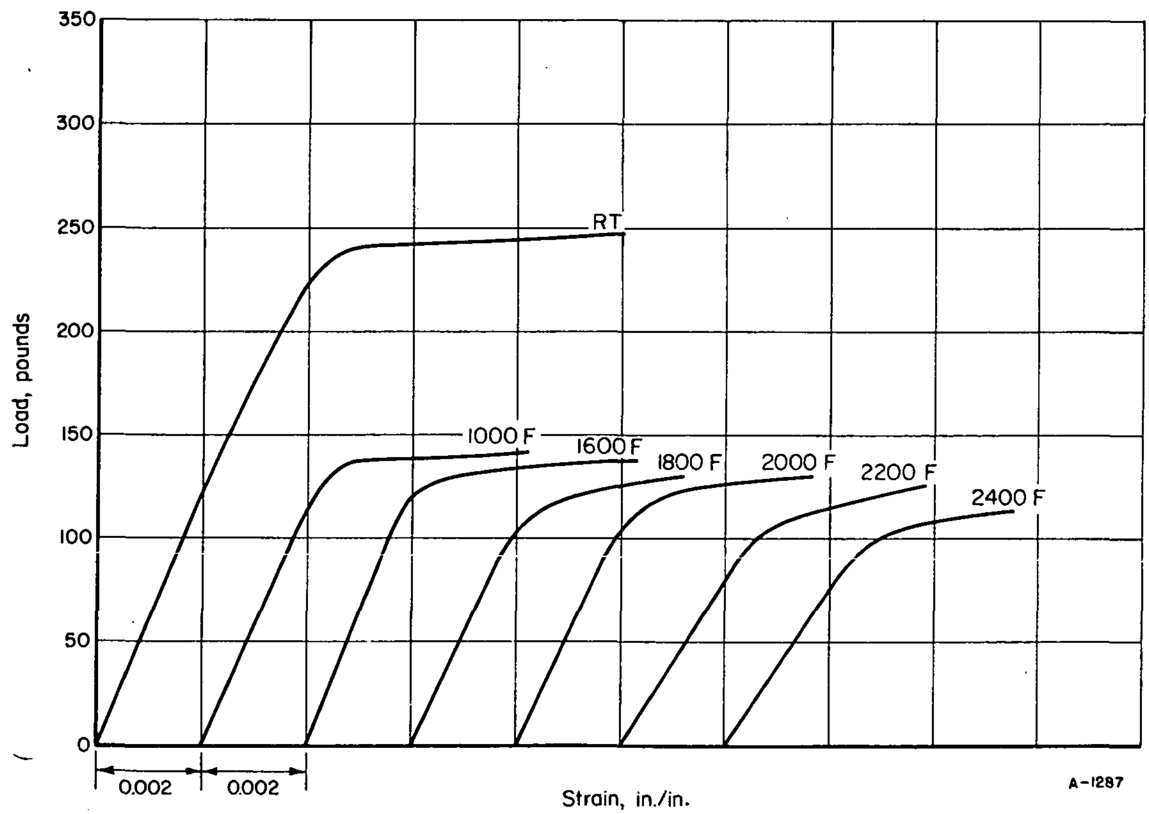


FIGURE 26. LOAD-STRAIN CURVES FOR VH109/C129Y AT VARIOUS TEMPERATURES

Posttest Materials Studies

Among the large number of specimens evaluated in this program, occasional specimens showed strengths and/or ductilities that were uncommonly high or low in comparison with other specimens from the tested group. A typical example of this behavior is isolated in Table 26. Simple inspection suggests that both the yield and ultimate strengths for Specimen 23-29 are abnormally low for this test series. A total of 10 such anomalies were observed. For each of these, attempts were made to establish the causes of the extreme differences. Tensile data were reexamined to exclude the possibility of error in reading the load-extension chart. Fractures were examined, for example, to define possible weld flaws or other irregularities. Finally, specimens were sectioned for metallographic measurement of coating and residual substrate thickness. The results of posttest evaluation of the ten specimens are described below.

TABLE 26. TENSILE PROPERTIES AT ROOM TEMPERATURE FOR VH109/C129Y EXPOSED TO 30 SIMULATED REENTRY CYCLES BEFORE TENSILE TESTING

Group and Specimen Number	Tensile Strengths Based on Original Specimen Dimensions, ksi		Tensile Elongation, percent
	F_{ty}	F_{tu}	
21-59	61.0	76.6	17
21-60	58.4	71.5	15
21-61	61.0	75.5	14
23-28	57.6	70.2	13
23-29	52.5	63.4	14

R512E/Cb752

Group 15, Specimen 2. This welded specimen, tested at room temperature, exhibited only 9.5 percent elongation contrasted to a range of 13 to 17 percent for nine other specimens in the test series. Fractography and metallography revealed that this specimen failed by brittle cleavage through the weld metal. All other specimens failed by ductile shear at the heat-affected zone or in the base metal. No evidence of a welding flaw was found. Microhardness (Vickers, 2-1/2-kg load) of the weld metal was 195, versus 203 for surrounding parent metal;

interstitial contamination during welding was ruled out. As no reason for this unusual behavior could be found, it was concluded that occasional "brittle" (despite the 9.5 percent elongation, uniform in this case) failures of welds in R512E/Cb752 must be anticipated, and the value was retained in the statistical evaluation. This behavior is not especially alarming, as weld strengths remained high.

Group 7, Specimen 9. This R512E/Cb752 specimen received ten simulated reentry cycles prior to tensile testing at 1000 F. Elongation was only 2 percent compared with 5 percent for all other specimens; ultimate strength accordingly was 31.1 ksi versus a range of 39.6 to 41.5 for other specimens of the test series. Fractography revealed a "dog-bone-shaped" fracture surface, with essentially no deformation at specimen edges near the fracture. In this region, the fracture surface was dimpled, but failure occurred in a plane that was oriented normal to the tensile stress axis. The specimen center (i.e., between the dog-bone ends) failed by ductile shear. All other specimens in this test series failed completely by means of ductile shear. A transverse section as near as possible to the fracture surface was prepared for metallographic examination. Total coating failure had occurred at one spot on the edge, allowing minor substrate oxidation, and contamination to a depth of 34 mils. Microhardness of the contaminated area (1 kg, Vickers) ranged from 265 at the limit of visible contamination to 500 near the breach in the coating, and was indicative of severe contamination. Substrate hardness was 190 in the uncontaminated area. No contamination was observed at the opposite edge, despite the symmetrical dog-bone fracture shape. The extent of contamination suggested that coating failure had occurred in fewer than five cycles. Because this was the only specimen from among the 80 specimens exposed to 5 or 10 cycles for which tensile data anomalies were observed for the R512E/Cb752 system, it was concluded that a premature random coating failure had occurred. Furthermore, because design allowables data for this program were not intended to include extreme value distribution events of this type, data from this specimen were not included in the design allowables treatment. It is encouraging to note that, despite early failure, yield strength at 1000 F was not affected, and elongation and ultimate strength were only modestly affected by the premature failure.

Group 4, Specimen 16. Thirty simulated reentry cycles preceded the room-temperature tensile test on this specimen. Tensile property comparisons in this test series were:

Specimen Number	Tensile Yield Strength, ksi	Tensile Ultimate Strength, ksi	Elongation, percent
4-16	55.2	57.6	3
4 others	52.0 - 53.8	61.8 - 62.9	10 - 12

Metallographic examination was conducted on all five specimens in this test series. Examination of Specimens 4-16 revealed a uniform, very dense precipitate in the substrate, indicative of mild but extensive contamination throughout the gage section which was also the hot section in simulated cycling.* No such indication of contamination was noted in any of the other specimens of this test series. From this, it was obvious that contamination that occurred during the pretest cyclic exposure in Specimen 4-16 caused strengthening, such that the yield strength at room temperature was increased, and a significant loss in ductility with a consequent decrease in the extent of strain hardening; hence, lower ultimate strength. Coatings on all specimens exhibited greater than expected oxidation and gross porosity throughout most of the coating layer.

This raised the question: was the behavior of Specimen 4-16 an isolated case? Examination of elevated-temperature tensile data for 30-cycle-exposed specimens revealed somewhat greater-than-normal scatter in strengths. Accordingly, all R512E/Cb752 specimens exposed to 30 cycles and selected specimens exposed to 10 cycles before tensile testing were prepared and examined metallographically. The net result was that 11 of the 19 specimens tested after 30 exposure cycles showed mild, but extensive, contamination such as noted for Specimen 4-16. For specimens tested at elevated temperatures, very limited "severe" contamination was noted at the base of coating cracks. This was induced during testing in air. The extent of contamination observed at these areas was related to the tensile test temperature, and suggested test contamination rates (assuming parabolic kinetics with time at temperature estimated by fractional elongation/strain rate) as follows:

Test Temperature, F	Estimated Contamination Rate, mil^2/min
2000	1.0
2200	1.4
2400	2.8

(For the limited amount of data involved, these rates compare reasonably well with expectations based on results obtained under Contract NAS8-26205.) As a consequence, it is quite certain that the extensive, mild contamination resulted from the pretest cyclic exposures. Several microhardness comparisons (1 kg Vickers) between uncontaminated and mild-contamination areas were made on several specimens with the following results:

Range of hardness for uncontaminated material	180 - 186
Range of hardness for mildly-contaminated material	201 - 219.

Thus, the degree of hardening was indeed slight and should hardly affect elevated-temperature properties, although it was apparently sufficient to cause significant degradation in room-temperature tensile ductility.

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* In Cb752, severe contamination, i.e., that associated with a hardness increase of 200 to 500 DPH, is indicated by (1) an absence of precipitation and (2) colored staining with the nitric-hydrofluoric-acetic acid mixture used for etching, neither of which was evident with these specimens; hence the word "mild" was considered descriptive.

All R512E/Cb752 specimens exhibited accelerated coating oxidation and gross coating porosity after 30 exposure cycles. After 10 cycles, mildly accelerated coating oxidation and gross porosity extending through roughly half the coating thickness was noted. None of the 10-cycle-exposed specimens examined showed extensive mild contamination. Several 30-cycle-exposed VH109/C129Y specimens were examined. These consistently showed less coating oxidation, little or no coating porosity, and no extensive substrate contamination such as was noted in the Cb752 substrate.

Studies under NAS8-26205 have subsequently shown by inference that the conditions of oxygen partial pressure under which the cyclic exposures of this program were made were substantially lower than suggested by the total pressure monitor. Although the intent in this cycling was to reasonably simulate the "external" shuttle TPS pressure environment, it is believed likely that the actual test oxygen pressure may have been closer to the "internal" pressure environment. At any rate, it was concluded that the R512E/Cb752 underwent wear-out failure under the cyclic exposure conditions which were used, in greater than 10, but less than 30 cycles, and that the wear-out process was low-oxygen-pressure volatilization of selected species of the R512E coating. Also, it may be speculated that diffusivity of oxygen in the Cb752 substrate under the cyclic exposure conditions is ample to prevent high oxygen gradients, thus avoiding development of severe, more degrading contamination sites in the substrate. The rate-controlling mechanism may be gas-phase diffusion or the rate of delivery of oxygen to the substrate surface.

It is further apparent that the VH109/C129Y system is able to withstand this cyclic environment for greater than 30 cycles.

The conclusion from this brief investigation is that for R512E/Cb752 specimens exposed to 30 cycles, the test data are representative of "failed" material, and as such should be viewed as distinct and separate from the balance of data generated for coated-columbium alloys. Most significant is that, although the R512E/Cb752 under these conditions has nominally failed, the consequences of failure are very mild and tensile properties, particularly yield strength, show very little or no degradation as a result of the failure (see Table 27), despite

TABLE 27. COMPARISON OF YIELD STRENGTHS OF AS-COATED AND 30-CYCLE-EXPOSED R512E/Cb752

Tensile Test Temp, F	Yield Strength (Method 2) Statistics				Fraction of Specimens "Failed" in 30-Cycle-Test Series
	As-coated		30 cycles		
	$\bar{x}$	s	$\bar{x}$	s	
RT	53.5	0.97	53.5	1.20	1/5
2000	29.8	0.82	28.7	0.46	2/4
2200	25.8	0.67	28.5	1.71	4/5
2400	24.8	0.65	26.1	1.82	5/5

the probable 10 to 15 cycles of exposure following the commencement of failure. The tentative design allowables based on "failed" material yield strengths are barely discernible from those based on virgin material, and probably fall within a normal scatter band for "unfailed" material design allowables (e.g., conditions other than 30-cycle exposed).

This, although an unintentional result, is perhaps the most significant finding of this study on coated-columbium alloys.

VH109/C129Y

Group 20, Specimen 1. This as-coated VH109/C129Y specimen was tensile tested at room temperature. High strengths were noted:

Specimen Number	Tensile Yield Strength, ksi	Tensile Ultimate Strength, ksi
20-1	65.1	81.1
9 Others	59.4 - 62.9	72.8 - 77.6

Metallographic measurement in the shoulder of the failed tensile specimen showed residual substrate thickness of 13.4 mils versus 13.6 mils expected for this Group. This cannot explain the observed anomaly. Results from this specimen from Heat 572038 would much better fit the statistics established for Heat 57006, but so far as is known, no such specimen mix-up occurred. Lacking a reason for the anomalous values, it was decided to include those results in the analysis.

Group 27, Specimen 1. As previously mentioned, this "welded" specimen tested at room temperature exhibited anomalously high yield and ultimate strengths and high elongation as well. Failure occurred by ductile shear away from the center of the reduced section (where the weld should have been). Metallography showed no weld in the test section. This "known" specimen mix-up was thus proven, and the results discarded. Strength values recalculated on the basis of Group 23 (to which this specimen truly belonged) instead of Group 27 substrate dimensions were compatible with the parent data of which they should have been a part.

Other VH109/C129Y Specimens. Five other irregularities were noted among the VH109/C129Y strength data. The appropriate specimens were sectioned longitudinally through the specimen shoulders to allow metallographic measurement of residual substrate thickness. It was anticipated that discrete low values for yield and ultimate strength might be explained by less than expected residual substrate based on original sheet (hence, Group) statistics, or less than for other specimens in the test series and vice versa. Table 28 summarizes the results of this investigation, and indicates that for all specimens, a major portion (in some cases, all) of the anomalies is indeed explained by unusual variation in the load-bearing residual substrate dimension. It is also apparent that the substrate thickness discrepancies resulted from coating thickness variations at or near the extreme distribution limits for the Groups involved. Underlying reasons for these anomalies, therefore, appear to reside in the somewhat high standard deviation of the VH109 coating process.

TABLE 28. VH109/C129Y SPECIMENS FOR WHICH TENSILE STRENGTHS WERE ANOMALOUSLY HIGH OR LOW

Group and Specimen Number	Test Series	Strength Deviation Versus Others in Test Series	Group Mean Thickness, mil		Metallographic Measured Mean Thickness, mil		Substrate Expected-to-Measured Deviation
			Residual Substrate	Coating	Residual Substrate	Coating	
27-19	Weld, 1300 F	20% Low	12.7	2.3	12.2	3.9	4% Low
27-28	Weld, 1600 F	20% Low	12.7	2.3	11.4	4.5	10% Low
21-31	10 Cycles, RT	8% High	13.4	2.5	13.3[a]	2.3	4% High[a]
21-39	10 Cycles, 2200 F	15% Low	13.4	2.5	12.0	3.5	10% Low
23-39	30 Cycles, RT	12% Low	12.8	2.9	11.4	3.7	11% Low

(a) Companion specimens for this test series were also measured and were 0.7 mil average less than expected regarding residual substrate.

The observed anomalies caused by coating variability extremes appeared to occur at random without regard to sheet or coating batch. The frequency of occurrence (5 out of 342 valid measurements) is low, but cannot be ignored. Because this appears to be a real feature of the present day VH109/C129Y system, these values were included for purposes of design allowables calculation. As can be seen in Table 20, the net result was significantly lower design allowable strengths for the five test series in which these anomalies occurred than for the majority of other equivalent (temperature) test series.

From these comments, it is obviously advantageous to upgrade the processing or quality control of coating operations for VH109/C129Y. That this is feasible is indicated by zero observations of this sort for the R512E/Cb752 system examined in parallel with the VH109/C129Y system.

DESIGN ALLOWABLES SUMMARY

The previous section and subsection contained the details of the analyses of the test data generated on this program. In this section of the report, the resultant information is presented as tentative allowables for the two coated-columbium-alloy systems. Several programs currently in progress will be providing additional data on essentially the same basic material and coating process. Combination of these data with those resulting from these additional programs should be done so that the tentative allowables contained herein can be brought to a firmer basis. The most critical problem associated with such a data consolidation in the near future will be related to potential processing variations that may occur, particularly in regard to the coatings.

In a document such as MIL-HDBK-5B, the format for design allowables is to indicate in a tabular array the room-temperature properties of a given alloy. This would include tensile, compression, shear, and bearing properties, including elongation, modulus values, and certain physical properties (unless shown on effect-of-temperature curves). Following this table would be a variety of graphs, first relating to effect of temperature on the basic allowables, then stress-strain curves, fatigue, and creep information.

In this section of the report, a somewhat similar arrangement has been constructed, with certain limitations: (1) tables and curves are concerned only with tensile properties; and, (2) the proposed allowables presently are based on material nominally 0.015 inch in original thickness with a nominal 0.003-inch-thick coating, the processing of which consumed some of the original substrate. Thus, the following design allowables are very specific to the material, the process, and the thickness. They are based on the original substrate dimension as stated several times in this report.* As such, they may not apply to thicker original substrates or to thicker or thinner coatings.

R512E/Cb752 Alloy System

This alloy was purchased in accordance with the chemical and mechanical property requirements described in Appendix A. As such, the two heats involved were received in the recrystallized annealed condition. In the case of Cb752, which in the past has been processed with a "duplex" annealing schedule, it is important to note that the material conformed to what is commonly called the "single annealed" condition. The coating was R512E, a fused-slurry-silicide coating, developed by and commercially available from Sylvania Electric Products, Inc. It was applied according to procedures existent in 1971 that provided a nominal coating thickness of 0.003 inch.

The room-temperature design allowables for this alloy/coating system are presented in Table 29 for the as-coated material.

Figures 27 and 28 show the effect of temperature on tensile ultimate and yield strength of the alloy/coating system. In these figures, the strength is shown as a percent of room-temperature strength in the longitudinal direction.

Figure 29 shows the effect of temperature on the elongation; the indicated values are in terms of elongation at temperature.

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* See sections entitled "Coated-Specimen Dimension Evaluation Procedures and Discussion" (page 15) for conversion factors for strength based on other cross-sectional area criteria.

TABLE 29. TENTATIVE ROOM-TEMPERATURE ALLOWABLES FOR R512E/Cb752 SYSTEM

Specification	None (see Appendix A)	
Product Form	Sheet	
Condition	Single recrystallized annealed	
Original Subtrate Thickness, inch	0.015	
Nominal Coating Thickness, inch (per side)	0.003	
Basis	A	B
Mechanical Properties[(a)]:		
F_{tu}, ksi	60	64
F_{ty}, ksi	50	52
e, percent	12	--
E_t, 10^3 ksi		
Primary	15.3	
Secondary	12.8	
Physical Properties[(b)]:		
ω, lb/in.^{3}	0.326	
c, Btu/(lb)(F)	0.067 (1000 F and 2400 F)	
K, Btu/[(hr)(ft^2)(F)/ft]	26 (1000 F); 29 (2400 F)	
α, 10^{-6} in/in/F	4.4 (RT to 2400 F)	

(a) Longitudinal properties.

(b) Base material only.

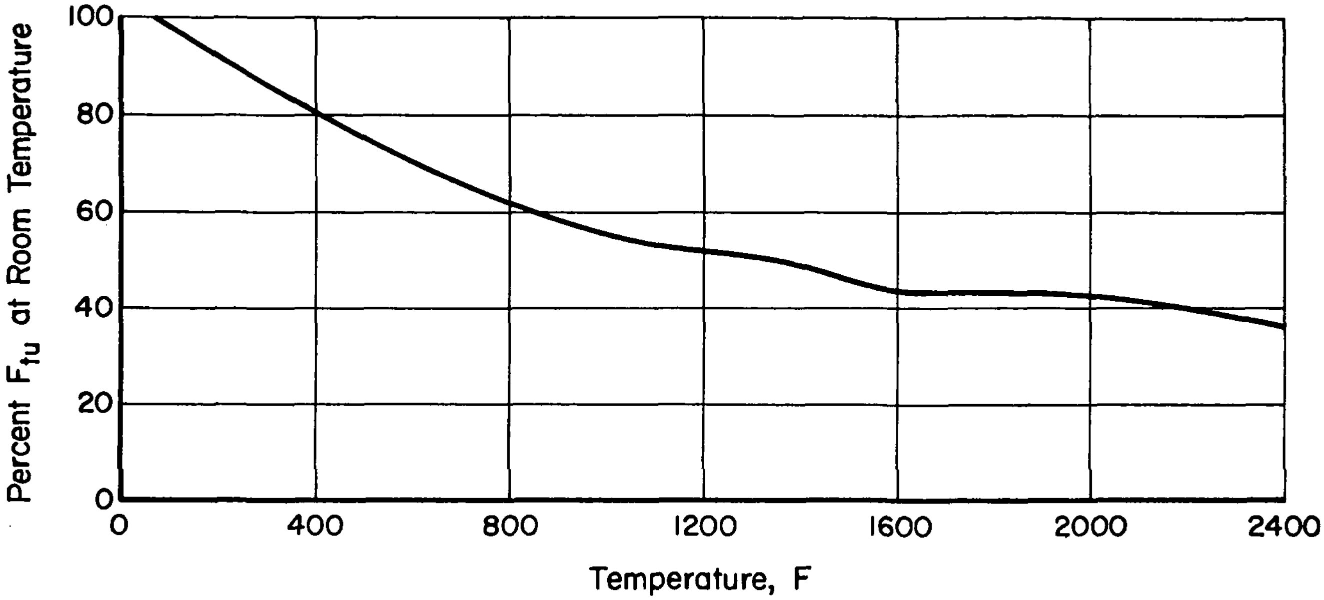

FIGURE 27. EFFECT OF TEMPERATURE ON THE TENSILE ULTIMATE STRENGTH OF R512E/Cb752 ALLOY (AS COATED)

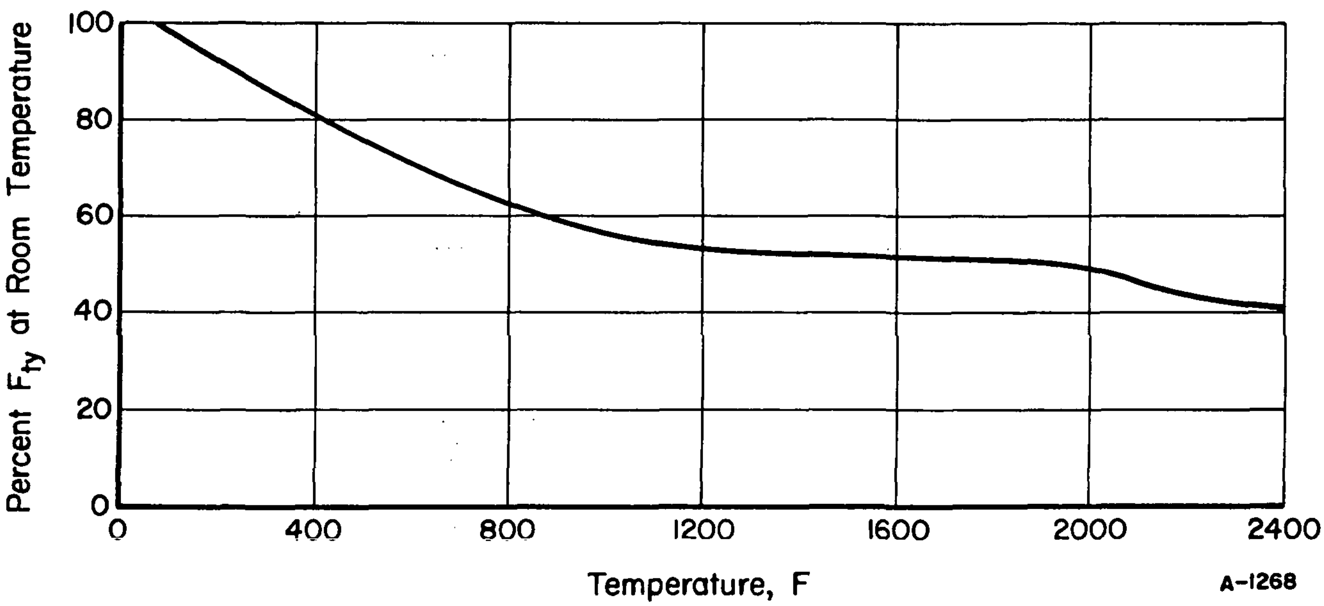

FIGURE 28. EFFECT OF TEMPERATURE ON THE TENSILE YIELD STRENGTH OF R512E/Cb752 ALLOY (AS COATED)

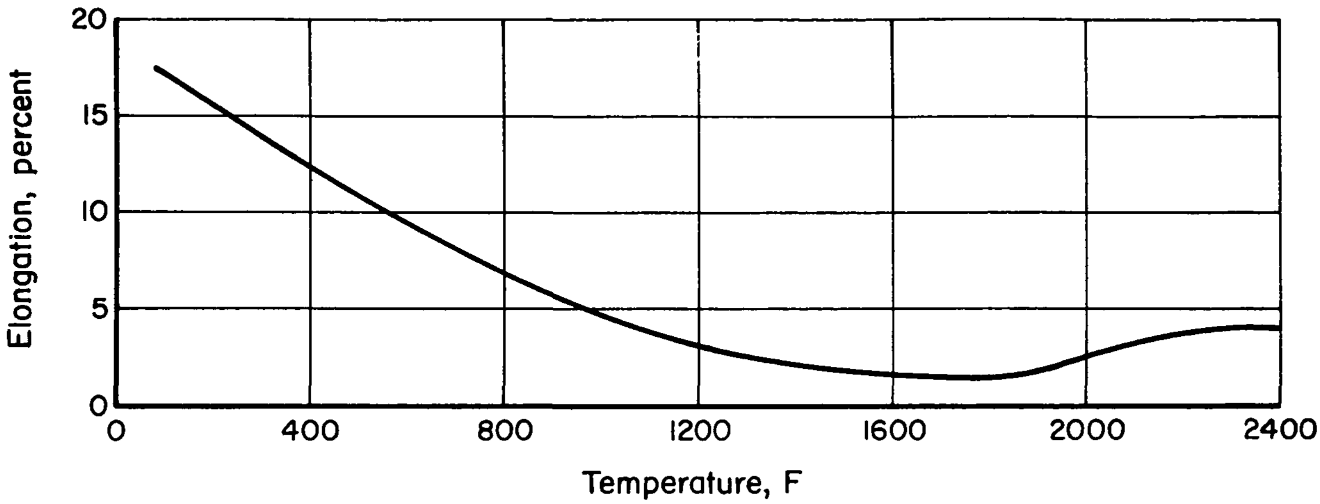

FIGURE 29. EFFECT OF TEMPERATURE ON THE ELONGATION OF R512E/Cb752 ALLOY (AS COATED)

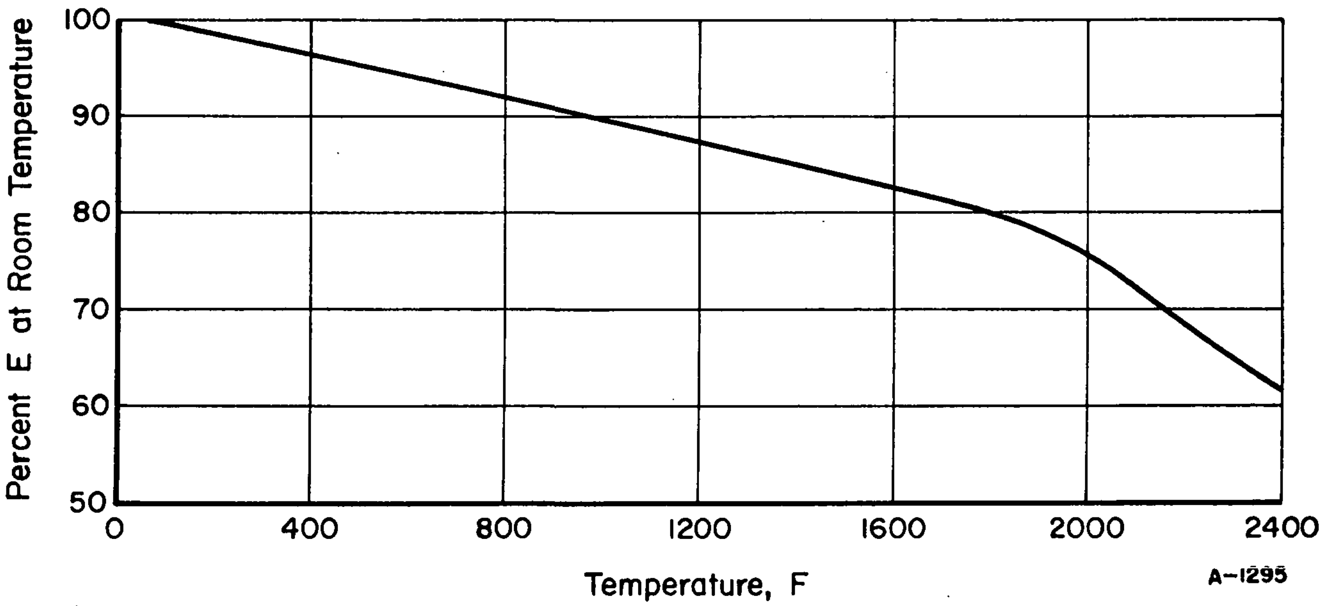

FIGURE 30. EFFECT OF TEMPERATURE ON THE TENSILE MODULUS OF ELASTICITY OF R512E/Cb752 ALLOY (AS COATED)

Figure 30 shows the effect of temperature on the tensile modulus of elasticity. It is shown as a percent of the room-temperature average modulus and applies only to the primary modulus.

Figure 31 shows typical stress-strain diagrams for several temperatures in the range of room temperature to 2400 F. These curves have not been modified by affine transformation to the average modulus or the average yield strength at the appropriate temperature.

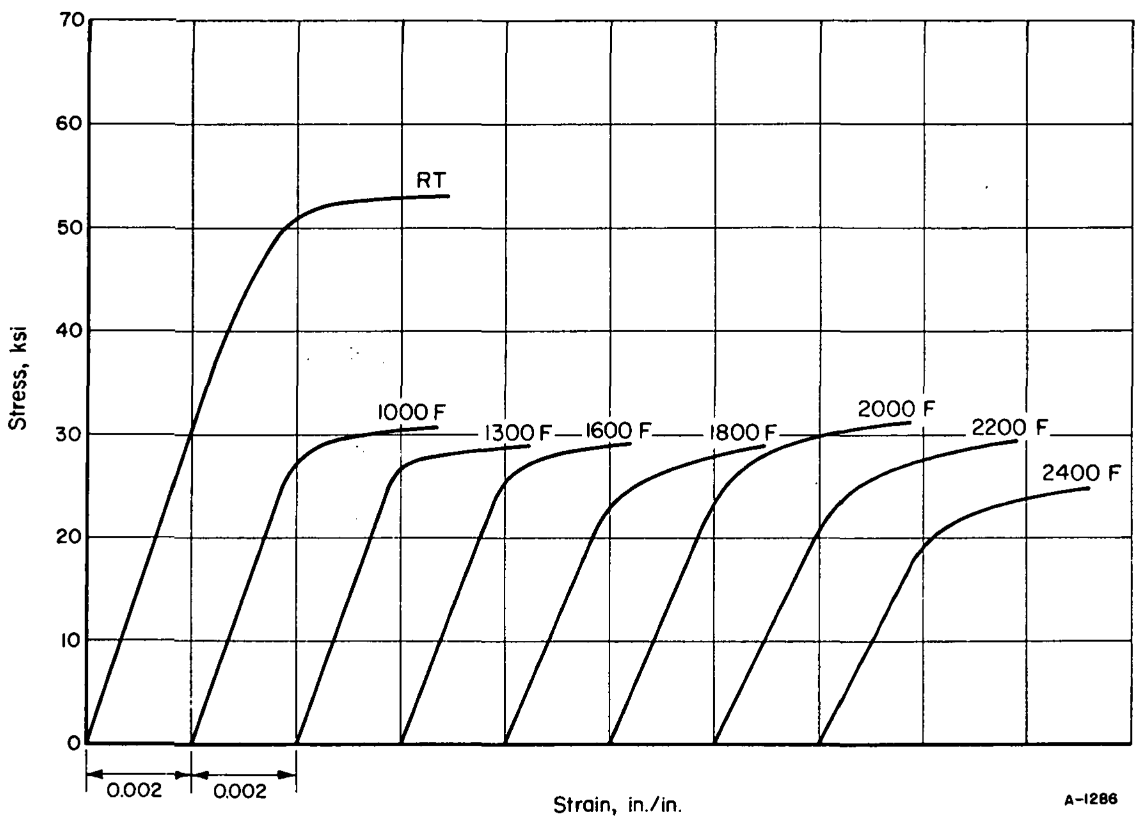

FIGURE 31. STRESS-STRAIN CURVES AT TEMPERATURE FOR R512E/Cb752 (AS COATED)

Table 30 shows fusion-welded joint efficiency factors for butt-welded joints. Included in this table are the welding parameters considered necessary to specify the welding process. These values are considered applicable over the temperature range of room temperature to 2400 F and are applied to the stress values obtained from Table 29 and Figures 27 and 28.

Table 31 shows the reduction factors applicable to the as-coated material associated with the T/P cycling, simulating reentry conditions. To use these reduction values at a given temperature, the tensile or yield strength values for the material are obtained from the tabular values in Table 29 (and multiplied by the percent room-temperature values from either

TABLE 30. FUSION-WELDED JOINT-EFFICIENCY FACTORS FOR R512E/Cb752 SYSTEM

Material	Single recrystallized annealed Cb752, 0.015 inch thick
Coating	R512E, 0.003 inch thick
Welding Details:	
Joint Configuration	Square butt, ground edges
Cleaning Procedures	Degreased, etched in nitric, hydroflouric, sulphuric acid solution, water rinsed
Fixturing	Weld joint centered on grooved copper backing plate, held by clamping bars separated by 1/4 inch
Atmosphere Control	Vacuum purge, backfilled with ultrahigh-purity helium
Welding Process	Gas-tungsten arc, direct current, straight polarity using 0.04-inch-diameter W-1ThO_2 electrode
Welding Parameters	Nominally 60 amperes at 17 volts and 30 inches/minute travel speed
Inspection	Visual, radiographic, and fluorescent penetrant
Weld Efficiency:	
Percent F_{tu}	96, room temperature to 2400 F
Percent F_{ty}	96, room temperature to 2400 F

TABLE 31. REDUCTION FACTORS[a] FOR AS-COATED R512E/Cb752 SYSTEM FOR T/P CYCLING

Material	Single recrystallized annealed Cb752, 0.015 inch thick		
Coating	R512E, 0.003 inch thick		
T/P Cycling Details:	Nominal Conditions:		
Heating	Ramp to 1400-1500 F in about 2 minutes		
Hold	1400-1500 F for 5 minutes		
Heating	Ramp to 2500 F in about 2 minutes		
Hold	2500 F for 15 minutes		
Cooling	Down to less than 1300 F, about 6 minutes		
Pressure	Pressure to increase linearly (with time) from 1 torr, at beginning of cycle, to 30 torr at end of 30-minute cycle		
Reduction Factors:	5 T/P Cycles	10 T/P Cycles	30 T/P cycles[b]
Percent F_{tu}	97	97	93
Percent F_{ty}	97	97	95

(a) These factors are applied to the room-temperature and elevated-temperature design allowables for as-coated Cb752 obtained from Figures 27 and 28 and Table 30.

(b) Coating wear-out failure has occurred; see text (pages 102 through 104).

Figure 27 or 28), and then are multiplied by the appropriate reduction factor from Table 31. It is also to be remembered that the values obtained with these reduction factors for 30 T/P cycles represent "failed" material in accordance with the discussion in the section entitled "Posttest Materials Studies". Even though this material had apparently failed by wear out of the coating, there was no really serious degradation in properties as shown by the reduction factors.

VH109/C129Y Alloy System

This alloy was purchased in accordance with the chemical and mechanical property requirements described in Appendix A. As such, the two heats involved were purchased in the single-annealed recrystallized condition. The coating was VH109, a fused-slurry-silicide coating that is applied in two separate coating stages (furnace fusion treatments). This coating was developed and is commercially marketed by Vac-Hyd Processing Corporation. It was applied according to procedures existent in 1971 that provided a nominal coating thickness of 0.003 inch.

The room-temperature design allowables for this alloy/coating system are presented in Table 32 for the as-coated material.

Figures 32 and 33 show the effect of temperature on tensile ultimate and yield strength. In these figures, the strength is shown as a percent of room-temperature strength in the longitudinal direction.

Figure 34 shows the effect of temperature on elongation. The indicated values are in terms of elongation at temperature.

Figure 35 shows the effect of temperature on the tensile modulus of elasticity. It is shown as a percent of the room-temperature average modulus and applies only to the primary modulus.

Figure 36 shows typical stress-strain diagrams for several temperatures in the range from RT to 2400 F. These curves have not been modified by affine transformation to the average modulus or the average yield strength at the appropriate temperature.

Table 33 shows fusion-welded joint efficiency factors for butt-welded joints. Included in this table are the welding parameters considered necessary to specify the welding process. These values are considered applicable over the temperature range from RT to 2400 F and are applied to the stress values obtained from Table 32 and Figures 32 and 33.

Table 34 shows the reduction factors applicable to the as-coated material associated with the T/P cycling, simulated reentry conditions. To use these values, the tensile or yield strength values at a given temperature for the material are obtained from the tabular values in Table 32 (and multiplied by the percent room temperature value from either Figure 27 or 28), and then are multiplied by the appropriate reduction factor from Table 34.

TABLE 32. TENTATIVE ROOM-TEMPERATURE ALLOWABLES FOR VH109/C129Y SYSTEM

Specification	None (see Appendix A)	
Product Form	Sheet	
Condition	Single recrystallized annealed	
Original Subtrate Thickness, inch	0.015	
Nominal Coating Thickness, inch (per side)	0.003	
Basis	A	B
Mechanical Properties[(a)]:		
F_{tu}, ksi	70	73
F_{ty}, ksi	57	59
e, percent	13	--
E_t, 10^3 ksi		
Primary	16.3	
Secondary	13.3	
Physical Properties[(b)]:		
ω, lb/in.^{3}	0.343	
c, Btu/(lb)(F)	0.069 (2400 F)	
K, Btu/[(hr)(ft^2)(F)/ft]	44.4 (2445 F)	
α, 10^{-6} in/in/F	4.5 (RT to 2200 F)	

(a) Longitudinal properties

(b) Base material only

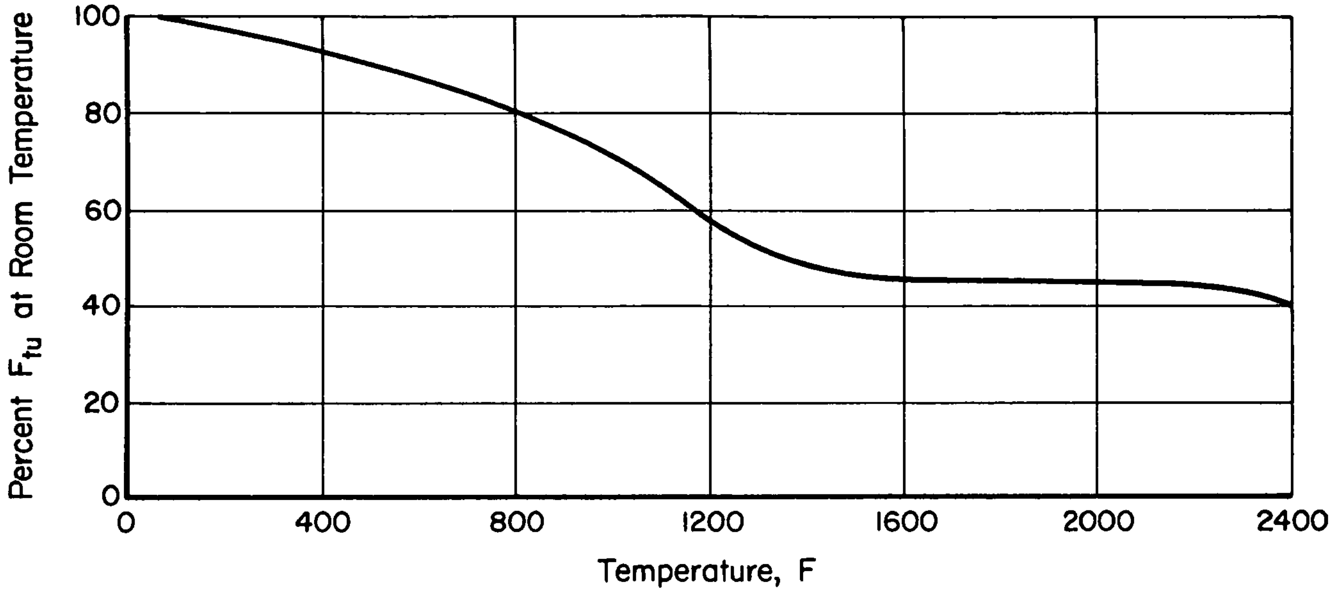

FIGURE 32. EFFECT OF TEMPERATURE ON THE TENSILE ULTIMATE STRENGTH OF VH109/C129Y ALLOY (AS COATED)

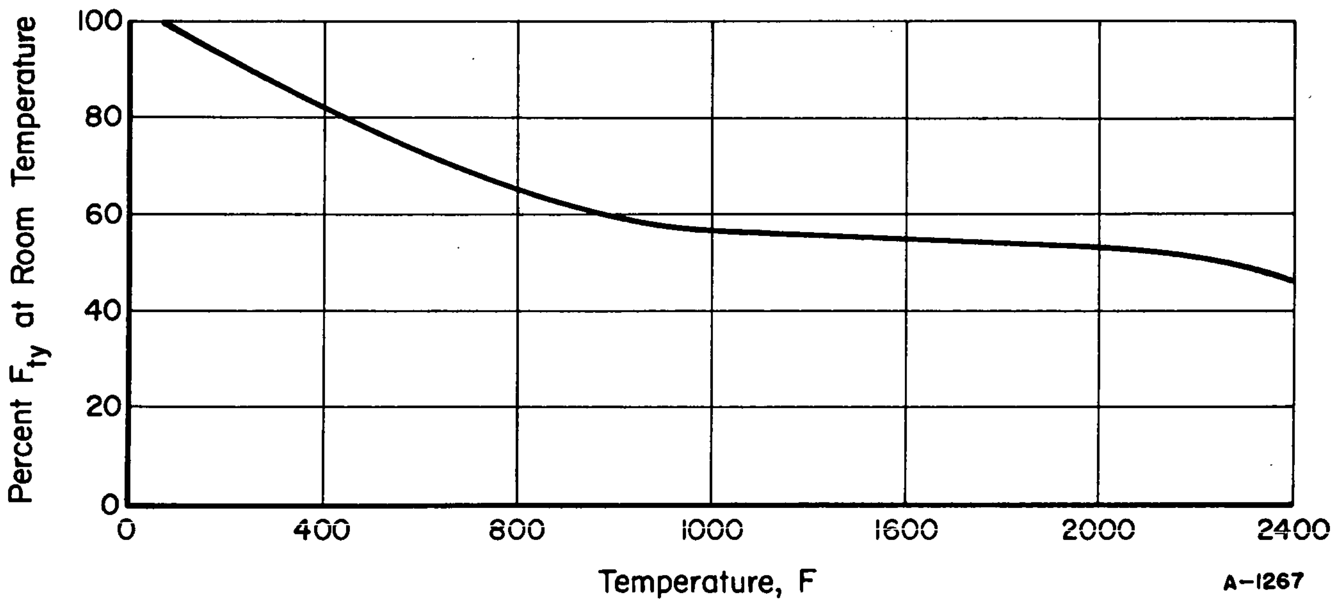

FIGURE 33. EFFECT OF TEMPERATURE ON THE TENSILE YIELD STRENGTH OF VH109/C129Y ALLOY (AS COATED)

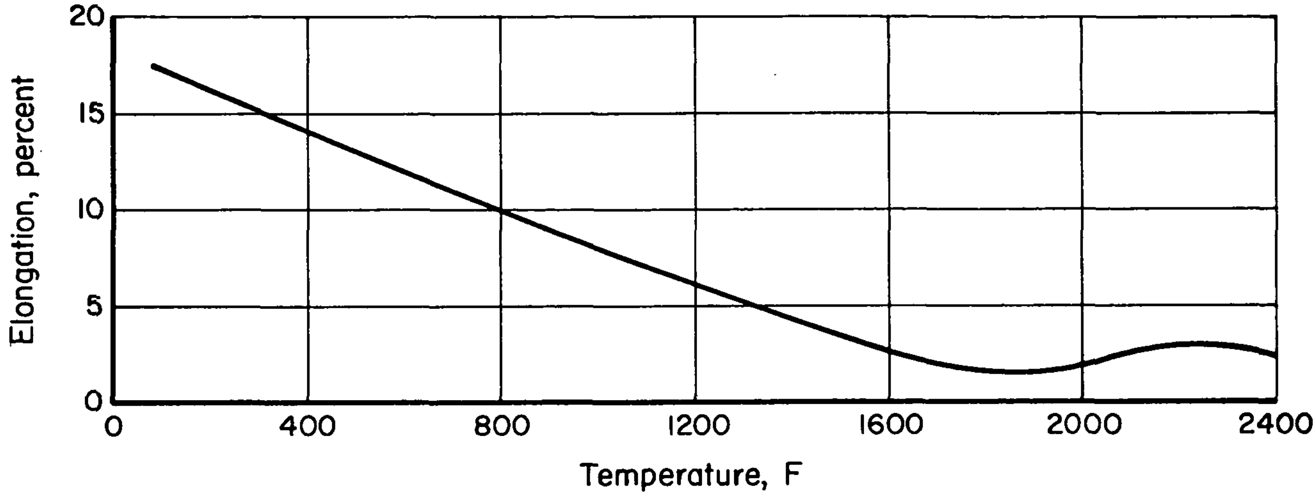

FIGURE 34. EFFECT OF TEMPERATURE ON THE ELONGATION OF VH109/C129Y ALLOY (AS COATED)

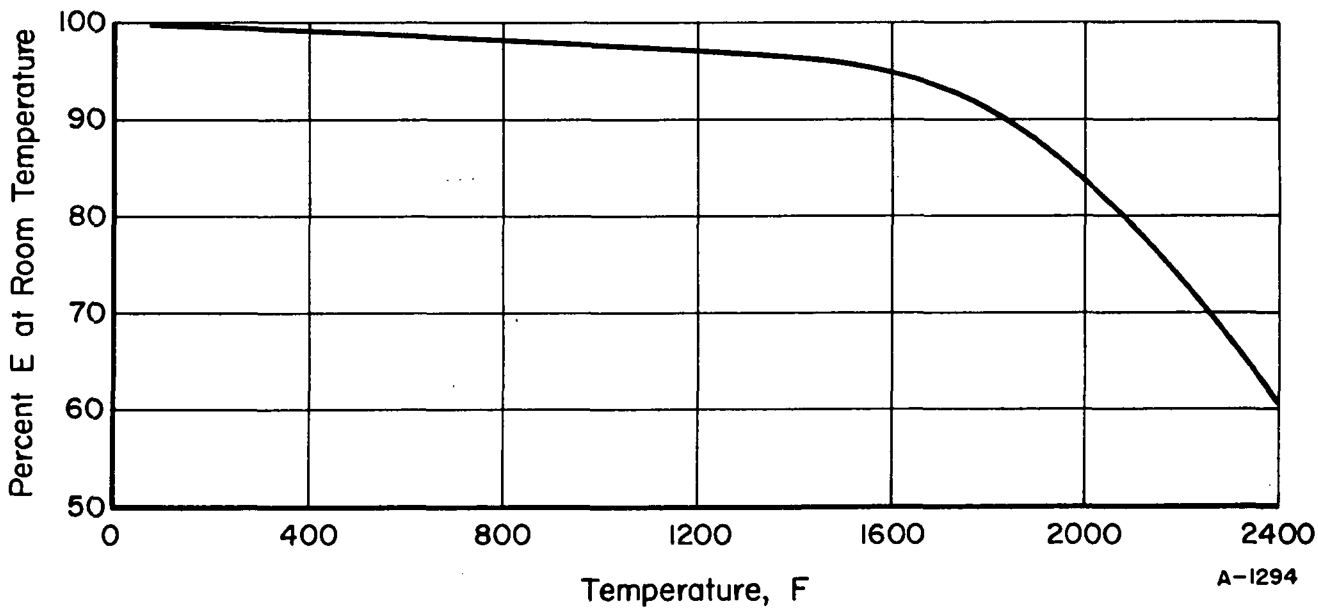

FIGURE 35. EFFECT OF TEMPERATURE ON THE TENSILE MODULUS OF ELASTICITY OF VH109/C129Y ALLOY (AS COATED)

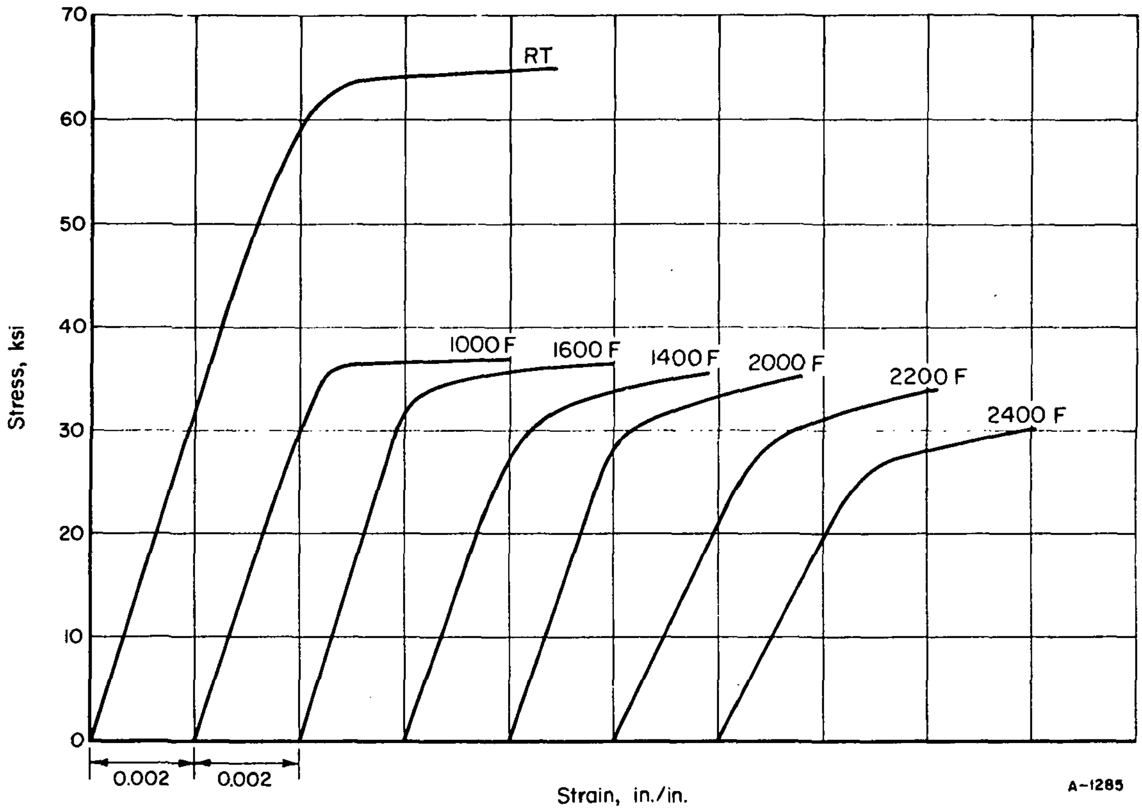

FIGURE 36. TYPICAL STRESS-STRAIN CURVES AT TEMPERATURE FOR VH109/C129Y (AS COATED)

TABLE 33. FUSION-WELDED JOINT EFFICIENCY FACTORS FOR VH109/C129Y SYSTEM

Material	Single recrystallized annealed C129Y, 0.015 inch thick
Coating	VH109, 0.003 inch thick
Welding Details:	
Joint Configuration	Square butt, ground edges
Cleaning Procedures	Degreased, etched in nitric, hydroflouric, sulphuric acid solution, water rinsed
Fixturing	Weld joint centered on grooved copper backing plate, held by clamping bars separated by 1/4 inch
Atmosphere Control	Vacuum purge, backfilled with ultrahigh-purity helium
Welding Process	Gas-tungsten arc, direct current, straight polarity using 0.04-inch-diameter W-1ThO_2 electrode
Welding Parameters	Nominally 60 amperes at 17 volts and 30 inches/minute travel speed
Inspection	Visual, radiographic, and fluorescent penetrant
Weld Efficiency:	
Percent F_{tu}	95, room temperature to 2400 F
Percent F_{ty}	97, room temperature to 2400 F

TABLE 34. REDUCTION FACTORS[(a)] FOR AS-COATED VH109/C129Y SYSTEM

Material	Single recrystallized annealed C129Y, 0.015 inch thick		
Coating	VH109, 0.003 inch		
T/P Cycling Details:	Nominal Conditions:		
Heating	Ramp to 1400-1500 F in about 2 minutes		
Hold	1400-1500 F for 5 minutes		
Heating	Ramp to 2500 F in about 2 minutes		
Hold	2500 F for 15 minutes		
Cooling	Down to less than 1300 F, about 6 minutes		
Pressure	Pressure to increase linearly (with time) from 1 torr, at beginning of cycle, to 30 torr at end of 30-minute cycle		
Reduction Factors:	5 T/P Cycles	10 T/P Cycles	30 T/P Cycles
Percent F_{tu}	95	95	95
Percent F_{ty}	97	96	96

(a) These factors are applied to the room-temperature and elevated-temperature design allowables for as-coated C129Y obtained from Figures 32 and 33 and Table 33.

CONCLUSIONS

In this part of the program, two coated-columbium-alloy systems, R512E/Cb752 and VH109/C129Y, were evaluated to establish tensile design properties for the (1) as-coated material and (2) butt-welded, as-coated material. In addition, the coating/alloy systems were subjected to 5, 10, and 30 temperature/pressure (T/P) cycles that were intended to simulate reentry conditions. The effect of the T/P cycles on tensile properties also was determined. During the program, considerable effort was expended to define statistically the coating thickness obtained from production processes and to determine the nature of substrate consumption as a consequence of the initial coating and subsequent T/P cycling. Extensive evaluation of the coating surfaces was conducted at all stages of the program.

The significant conclusions of this study are as follows:

(1) Room-temperature and elevated-temperature (up to 2400 F) design allowables have been developed and presented for R512E/Cb752 and VH109/C129Y systems. At the present time, these allowables are considered to be tentative values and are specific to an initial substrate thickness of 0.015 inch and a nominal coating thickness of 0.003 inch.

(2) Butt-welds, produced as described herein, provide nearly 100 percent weld efficiencies; specifically, weld efficiencies for R512E/Cb752 for both tensile and yield strength were 96 percent; whereas for VH109/C129Y, the weld efficiency for tensile ultimate strength was 95 percent and that for tensile yield strength was 97 percent. These efficiencies are considered to apply over the temperature range RT to 2400 F.

(3) T/P cycling also provides some reduction in design strength values. For R512E/Cb752, this reduction factor is 97 percent for tensile yield and ultimate strengths for up to 10 T/P cycles; for VH109/C129Y the greatest reduction factor was 95 percent for tensile ultimate strength and 96 percent for tensile yield strength. These values also are considered to apply over the temperature range RT to 2400 F.

(4) For R512E, coating wear-out failure occurred between 10 and 30 T/P cycles in the simulated reentry environment which provided a further slight decrease in strength to reduction factors of 93 percent for tensile ultimate strength and 95 percent for tensile yield strength.

(5) The design allowables information is based on the original uncoated substrate area. As such, the values may apply only to 0.015-inch substrate. As other significant data accumulations develop, the extension of this limitation can

be tested. In such evaluations, a detailed study of substrate thickness effect on tensile properties should be made based on residual substrate dimensions.

(6) Several NASA-sponsored programs, currently in progress and identified in this report, are expected to provide data for addition to this compilation. Combination of these additional data with the present data base should be done and may be sufficient to provide firm design allowables.

(7) With regard to coating thickness measurements, the mean thickness of VH109 was found to be 2.51 mils with a standard deviation, s, of 0.40 mil; whereas those for R512E were 3.41 mils and 0.27 mil. Thus, the VH109 generally was a thinner coating with greater variability than for R512E.

(8) The specific results show VH109/C129Y to have higher design strength values over the range of temperature studied than does R512E/Cb752. In part, this relates to the higher strength of uncoated C129Y compared with Cb752, and, in part, to the fact that the average coating thickness of VH109 was less than that of R512E.

(9) The test results also indicate greater variability in strength for the VH109/C129Y system than for the R512E/Cb752 system. This reflects, it is believed, the higher variability in coating thickness for VH109 in comparison with R512E.

(10) Based on the measurements of coating thickness, factors are provided in the report to estimate substrate consumption and to evaluate stress area based on remaining substrate.

(11) In evaluating test results of all T/P cycled materials, only one irregularity was observed that was traced to premature coating failure. Thus, since about 190 specimens (excluding 30 T/P cycled R512E/Cb752) were tested, this indicates coating reliability of greater than 99 percent for the overall systems investigated.

(12) The observation of extensive (but mild) substrate contamination in many of the R512E/Cb752 specimens exposed to 30 T/P cycles strongly indicates that wear out occurred in less than (or about) 30 cycles under the cycling conditions used. These may be more representative of "internal" than the intended "external" pressure condition. Most significantly, as indicated in Conclusion 4, the resulting mild contamination had only barely discernible effects on the material properties.

(13) With regard to further property evaluations beyond present programs, it appears necessary to develop design data in compression, including stress-strain and tangent-modulus curves. Examination of fatigue behavior (primarily low-cycle fatigue at high temperature and high-cycle fatigue at low temperatures) of the coated alloy systems should be done. Creep/fatigue interaction effects should be studied.

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(2) Bilow, G., "Refractory Metals Processing Methods", McDonnell Douglas Corporation, St. Louis, Missouri, Report G655, EMA-BED-744, December 15, 1968.

(3) Priceman, S., and Sama, L., "Development of Fused Slurry Silicide Coatings for the Elevated-Temperature Oxidation Protection of Columbium and Tantalum Alloys", Sylvania Electric Products Inc., Hicksville, New York, Technical Report AFML-TR-68-210 under Contract AF 33(616)-3272, December, 1968.

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(5) Robinson, M. L., "Evaluation of Coated Columbium Alloys for Burner Applications", Pratt and Whitney Aircraft, Division of United Aircraft, East Hartford, Connecticut, Report PWA-3907 under Contract F33615-69-C-1634, April 17, 1970.

(6) Fitzgerald, B., "Evaluation of the Fused Slurry Silicide Coating Considering Component Design and Reuse", McDonnell Douglas Corporation, St. Louis, Missouri, Report G658 under Contract F33615-67-C-1574, November 15, 1968.

(7) Robinson, M. L., "Evaluation of Coated Columbium Alloys for Burner Applications", Pratt and Whitney Aircraft, Division of United Aircraft, East Hartford, Connecticut, Report PWA-3978 under Contract F33615-69-C-1634, July 17, 1970.

(8) Baer, J. W., and Black, W. E., "Reentry Spacecraft Columbium Alloy Components Development", General Dynamics, Convair Division, San Diego, California, paper presented at the 17th Refractory Composites Working Group Meeting, Williamsburg, Virginia, June 16-18, 1970.

(9) Private Communication, General Dynamics, Convair Division, San Diego, California, August 6, 1970.

(10) Private Communication, General Electric Company, Space Technology Center, Valley Forge, Pennsylvania, August 27, 1970.

(11) Private Communication, North American Rockwell, Space Division, Downey, California, August 24, 1970.

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(16) Allen, B. C., Bartlett, E. S., and Wilcox, B. A., "Elevated Temperature Ductility Minima and Creep Strengthening of Coated and Uncoated Columbium Alloys", AFML-TR-66-89, Part II, February, 1967.

APPENDIX A

PROCUREMENT SPECIFICATION FOR Cb752 AND C129Y ALLOYS

APPENDIX A

PROCUREMENT SPECIFICATION FOR Cb752 AND C129Y ALLOYS

1. Scope

1.1. Scope. This specification establishes the requirements for columbium alloy plates, sheets, and strip.

1.2. Classification. Columbium alloy plates, sheet, and strip procured to this specification shall be supplied in the following types:

Type	Composition
C129Y	Cb-10Hf-10W-0.1Y
Cb752	Cb-10W-2.5Zr

2. Applicable Documents

2.1. The following documents of the issue in effect on the date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

Standards

Federal

Federal Test Method Standard No. 151	Metals; Test Methods
MIL STD 271	Non-Destructive Testing (X-ray, Sonics, Dye Penetrant)

American Society for Testing Materials

ASTM-E112	Methods for Determining Average Grain Size

National Academy of Science

Material Advisory Board MAB-216-M	Evaluation Test Methods for Refractory Metal Sheet Material

Aeronautical Material Specifications

AMS2242C Tolerances

3. Requirements

3.1. Materials.

3.1.1. Production Methods. The ingot metal shall be double vacuum melted in a furnace of a type suited for reactive metals. The starting ingot shall be free of voids and defects as determined by ultrasonic inspection.

3.1.2. Alloy Identification. The identity of all alloys with respect to ingot melt number shall be maintained at all stages of fabrication.

3.1.3. Condition. Unless otherwise specified, all material shall be supplied in the recrystallized annealed condition in accordance with Table A-1.

TABLE A-1.

Thickness	% Recrystallization C129Y	% Recrystallization Cb752
Less than 0.005	A/W	A/W
0.005 – 0.150	95-100	95-100
0.151 – 0.250	90-100	90-100
0.251 – 1.00	85-100	85-100

3.2. Chemical Composition. The chemical composition of each alloy ingot shall conform to Table A-2.

TABLE A-2.

Element	C129Y	Cb752
Tungsten	9-11%	9-11%
Hafnium	9-11%	2000 ppm*
Tantalum	5000 ppm*	5000 ppm*
Yttrium	0.1-0.3%	--
Titanium	--	--
Zirconium	5000 ppm*	2.2-2.8%
Carbon	150 ppm*	150 ppm*
Oxygen	225 ppm*	200 ppm*
Nitrogen	100 ppm*	100 ppm*
Hydrogen	15 ppm*	15 ppm*
Columbium	Balance	Balance

* Maximum limits unless otherwise indicated. ppm = parts per million.

3.2.1. Product Analysis. If specified, product analysis shall be performed on C, O_2, N with maximum levels specified as follows in parts per million (ppm):

Element	C129Y	Cb752
C	150	150
O_2	225	225
N	100	100

3.3. Tensile Properties. Elongation, yield strength, and ultimate tensile strength shall be measured at room temperature on samples transverse to final rolling direction, on material which is 0.010 inch thick or greater. The strain rate shall be maintained at 0.005 ± 001 inch/inch/minute through the 0.2 percent offset yield strengths and at 0.05 ± 0.005 inch/inch/minute thereafter. The material shall have minimum transverse tensile property values as specified in Table A-3.

TABLE A-3.

	C129Y	Cb752
Ultimate Tensile Strength, 1000 psi	80	75
Yield Strength, 0.2% offset, 1000 psi	60	55
Elongation, % in 1 inch	20	20

3.4. Bend Ductility. Representative samples of the materials in final form shall withstand the following bend test at room temperature without failure when tested according to procedures described in the most recent revision of the Materials Advisory Board Report MAB-216-M, "Evaluation Test Methods for Refractory Metal Sheet Materials". The samples shall be sectioned with the long axis of the bend specimens perpendicular to the final rolling direction.

3.4.1. Sheet 0.060 inch in thickness and under shall be bent over a 1-T radius through 105 degrees at a ram speed of 1 inch/minute and subsequently flattened for a total bend of 180 degrees.

3.4.2. Sheet over 0.060 inch to 0.187 inch in thickness shall be bent over a 1-T radius through 105 degrees at a ram speed of 1 inch/minute.

3.5. Grain Size. Unless otherwise specified, the minimum average ASTM grain size number shall be in accordance with Table A-4.

TABLE A-4.

Thickness	C129Y	Cb752
0.006-0.150 inch	6	6
0.151-0.500 inch	5	5

4. Dimensions and Tolerances

4.1. Dimensions and Tolerances. Unless otherwise specified, tolerances shall be as defined in AMS2242C.

4.2. Flatness. Total deviation from flatness of sheet and strip shall not exceed 6 percent as determined by the following formula:

$$\frac{H}{L} \times 100 = \text{percent of flatness deviation}$$

where

H = maximum distance from a flat reference surface, and

L = minimum distance from this point to the point of contact with the reference surface.

4.3. Marking for Identification. Each plate, sheet, and strip shall be suitably marked with the contract number or order number, ingot melt number, specification number, and composition number.

5. Quality.

5.1. General. The finished product shall be visibly free from oxide or scale of any nature, grease, oil, residual lubricants, and other extraneous materials. Cracks, laps, seams, gouges, and fins shall be unacceptable.

5.2. Surface Rework. All surface pores, gouges, and other defects deeper than 0.005 inch or 3 percent of the thickness, whichever is smaller, shall be unacceptable. Surface imperfections may be faired smooth to remove any notch effect provided dimensional tolerances are still maintained.

5.3. Edge. The edges shall be produced by shearing, slitting, or sawing. The burr height shall not exceed 5 percent of the thickness of the material.

6. Reports. The supplier shall submit three certified copies of reports indicating the ingot chemistry. In addition, the material will be certified, but not tested to this specification. Additional tests for tensile, yield, elongation, and grain size, and product analysis for oxygen, carbon, and nitrogen will be furnished when specified in the purchase order.

7. Preparation for Delivery.

7.1. Packaging. All material shall be packaged in a manner that will prevent damage in transit and in storage.

8. Rejections. Material not conforming to any of the requirements of this specification unless otherwise agreed upon by the purchases.

9. Definitions. For the purposes of this specification, the following definitions shall apply.

9.1. Sheet. Sheet is flat, rolled material up to 0.125 inch thick, normally supplied in widths over 12 inches.

9.2. Plate. Plate is flat, rolled material 0.125 inch thick or greater.

9.3. Strip. Strip is flat, rolled material up to 0.060 inch thick in widths under 12 inches.

APPENDIX B

ORIGINAL TENSILE TEST DATA

APPENDIX B

ORIGINAL TENSILE TEST DATA

The tables in Appendix B contain the basic information derived from the test program conducted on the two coated columbium alloy systems.

Each table is for one set of data, wherein a set is defined by the coating/alloy system, the material condition parameter, and the test temperature. The tables are arranged in identical order and contain seven columns, identified as shown below:

Column 1 — Group number — see Figures 2 and 3 for identification

Column 2 — Specimen number

Column 3 — Specimen width, inch — measured with flat micrometers

Column 4 — Specimen thickness, inch — measured with flat micrometers

Column 5 — Ultimate load, pounds — given to three significant figures

Column 6 — Yield load, pounds — given to three significant figures

Column 7 — Elongation, percent.

Eight tables are available for each coating/alloy system and material condition as explained in the text. These eight tables are presented in order of ascending temperature. To provide some facility in locating specific tables, the following tabulation is provided:

R512E/Cb752

As Coated	Tables B-1 — B-8
Welded and Coated	Tables B-9 — B-16
As Coated, 5 T/P Cycles	Tables B-17 — B-24
As Coated, 10 T/P Cycles	Tables B-25 — B-32
As Coated, 30 T/P Cycles	Tables B-33 — B-36

VH109/C129Y

As Coated	Tables B-37 — B-44
Welded and Coated	Tables B-45 — B-52
As Coated, 5 T/P Cycles	Tables B-53 — B-60
As Coated, 10 T/P Cycles	Tables B-61 — B-68
As Coated, 30 T/P Cycles	Tables B-69 — B-74

TABLE B-1. R512E/CB752, AS COATED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
14	1	0.255	0.021	275.	205.	17.0
14	2	0.254	0.020	267.	203.	17.0
14	3	0.255	0.021	278.	213.	14.0
14	4	0.254	0.020	275.	210.	17.0
14	5	0.254	0.021	272.	207.	16.0
14	6	0.255	0.021	276.	213.	18.0
14	7	0.254	0.020	269.	206.	17.0
14	8	0.254	0.020	270.	206.	15.0
14	9	0.254	0.020	273.	208.	18.0
14	10	0.255	0.020	275.	212.	17.0
2	7	0.252	0.020	256.	202.	19.0
5	25	0.252	0.020	246.	196.	20.0
5	26	0.253	0.020	250.	200.	20.0
6	13	0.253	0.020	256.	205.	19.0
6	14	0.253	0.020	252.	200.	18.0
7	31	0.252	0.020	254.	205.	19.0
7	32	0.252	0.020	248.	198.	16.0
8	1	0.252	0.020	255.	200.	20.0
8	11	0.252	0.020	255.	200.	17.0
8	11	0.253	0.020	246.	194.	19.0

TABLE B-2. R512E/CB752, AS COATED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
2	1	0.251	0.020	148.	113.	5.0
2	17	0.252	0.020	148.	122.	4.0
2	18	0.252	0.020	143.	117.	4.0
2	19	0.252	0.021	155.	123.	5.0
2	3	0.252	0.020	138.	113.	5.0
3	8	0.254	0.020	143.	115.	4.0
5	27	0.253	0.021	143.	115.	5.0
5	28	0.253	0.021	145.	112.	7.0
6	15	0.253	0.020	139.	115.	4.0
7	33	0.252	0.020	158.	120.	7.0
7	34	0.251	0.019	143.	116.	4.0
8	12	0.252	0.020	152.	120.	4.0
10	12	0.253	0.020	161.	119.	6.0
11	2	0.253	0.019	161.	118.	4.0
14	11	0.255	0.020	152.	118.	4.0
14	12	0.254	0.020	164.	124.	5.0
14	13	0.253	0.020	158.	122.	4.0
14	14	0.256	0.021	160.	124.	5.0
14	15	0.255	0.021	162.	123.	6.0
14	35	0.255	0.021	162.	131.	5.0
14	36	0.255	0.021	150.	117.	4.0
14	37	0.255	0.021	167.	125.	4.5
14	38	0.254	0.020	158.	117.	5.0
14	39	0.254	0.020	156.	117.	5.0

TABLE B-3. R512E/CB752, AS COATED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
1	4	0.253	0.020	139.	117.	3.0
1	5	0.253	0.020	131.	111.	3.5
1	6	0.254	0.021	137.	117.	1.5
3	7	0.255	0.020	125.	109.	3.5
3	10	0.253	0.020	127.	111.	3.0
9	4	0.252	0.020	130.	109.	3.5
9	5	0.252	0.020	125.	107.	2.0
9	6	0.252	0.020	128.	108.	2.0
11	3	0.254	0.020	134.	111.	3.0
11	4	0.254	0.020	128.	110.	4.0
13	4	0.255	0.020	138.	117.	1.0
13	5	0.255	0.020	138.	117.	1.0
13	6	0.255	0.021	140.	117.	2.0
14	16	0.255	0.021	144.	118.	3.0
14	17	0.255	0.021	140.	118.	2.0
14	18	0.255	0.021	138.	118.	2.0
14	19	0.254	0.021	139.	118.	4.0
14	20	0.254	0.021	144.	118.	3.0
14	41	0.254	0.021	136.	115.	1.0
14	42	0.254	0.021	137.	115.	2.0

TABLE B-4. R512E/CB752, AS COATED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
1	7	0.254	0.020	114.	111.	2.0
1	8	0.253	0.020	118.	111.	3.0
1	9	0.254	0.021	121.	117.	2.5
1	10	0.254	0.021	122.	118.	2.0
3	9	0.254	0.020	117.	112.	2.0
5	35	0.252	0.020	111.	107.	2.0
9	7	0.253	0.020	115.	111.	2.5
9	8	0.252	0.020	113.	108.	3.0
9	9	0.252	0.020	114.	111.	2.0
9	10	0.252	0.020	110.	109.	2.0
11	1	0.253	0.020	117.	113.	2.0
13	1	0.255	0.021	127.	124.	2.0
13	2	0.255	0.021	127.	124.	3.0
13	3	0.255	0.020	125.	123.	3.0
13	7	0.255	0.021	140.	135.	3.0
14	25	0.255	0.020	126.	126.	1.0
14	26	0.255	0.020	125.	124.	3.0
14	27	0.255	0.020	130.	127.	1.0
14	4	0.255	0.021	121.	121.	2.0
14	63	0.256	0.021	123.	121.	1.5
14	70	0.255	0.021	121.	118.	2.0

TABLE B-5. R512E/CB752, AS COATED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
1	1	0.254	0.021	117.	115.	1.0
1	2	0.254	0.021	129.	126.	1.0
1	3	0.254	0.020	113.	110.	2.0
2	23	0.252	0.020	123.	118.	1.0
2	24	0.252	0.020	121.	113.	0.0
4	19	0.254	0.020	116.	113.	2.0
9	1	0.253	0.020	113.	108.	2.0
9	2	0.253	0.020	118.	115.	1.0
9	3	0.253	0.020	115.	110.	2.0
11	5	0.254	0.020	115.	113.	2.0
11	6	0.253	0.020	112.	108.	1.0
13	8	0.254	0.020	124.	120.	1.0
13	9	0.254	0.020	136.	129.	2.0
13	1	0.253	0.020	125.	119.	2.0
14	46	0.255	0.021	126.	115.	1.0
14	47	0.254	0.020	126.	115.	2.0
14	48	0.255	0.021	127.	122.	1.5
14	49	0.254	0.020	126.	121.	1.0
14	50	0.254	0.021	127.	123.	0.5
14	51	0.254	0.020	128.	122.	1.0
14	52	0.254	0.020	131.	126.	2.0

TABLE B-6. R512E/CB752, AS COATED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
2	25	0.252	0.020	111.	107.	2.5
5	29	0.252	0.021	117.	113.	2.5
5	31	0.252	0.020	114.	109.	2.5
6	16	0.253	0.020	118.	111.	3.0
6	17	0.253	0.020	115.	109.	3.0
7	35	0.252	0.020	121.	114.	2.0
7	36	0.252	0.020	121.	115.	2.0
8	13	0.252	0.021	122.	115.	3.0
8	14	0.252	0.020	122.	114.	3.0
10	13	0.254	0.020	114.	109.	3.0
14	28	0.255	0.021	132.	128.	2.0
14	29	0.255	0.021	135.	126.	4.0
14	3	0.254	0.020	117.		4.0
14	31	0.256	0.021	134.	126.	3.0
14	32	0.255	0.021	129.	123.	2.0
14	53	0.254	0.020	129.	127.	2.0
14	54	0.256	0.021	126.	123.	2.0
14	55	0.254	0.021	127.	122.	2.5
14	56	0.254	0.020	127.	122.	2.5
14	57	0.255	0.020	129.	125.	3.0

TABLE B-7. R512E/CB752, AS COATED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
2	12	0.251	0.020	112.	97.	4.0
2	13	0.252	0.020	115.	99.	4.5
2	14	0.252	0.020	114.	98.	4.0
5	33	0.251	0.020	115.	98.	3.5
5	34	0.251	0.020	111.	97.	4.0
10	15	0.254	0.020	114.	97.	4.5
10	16	0.253	0.020	107.	90.	3.5
10	2	0.253	0.020	114.	96.	3.5
11	7	0.254	0.020	117.	98.	4.5
11	8	0.254	0.020	117.	97.	3.0
14	33	0.255	0.020	131.	110.	3.5
14	34	0.255	0.021	136.	111.	4.5
14	43	0.255	0.021	137.	110.	3.5
14	44	0.255	0.021	132.	112.	4.0
14	45	0.255	0.021	133.	112.	3.0
14	64	0.254	0.021	135.	114.	3.0
14	65	0.255	0.021	135.	111.	4.0
14	66	0.255	0.021	135.	111.	3.5
14	67	0.255	0.021	138.	112.	3.0
14	68	0.254	0.020	135.	113.	4.0

TABLE B-8. R512E/CB752, AS COATED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
2	15	0.252	0.020	104.	93.	5.0
5	3	0.252	0.021	96.	93.	3.0
6	18	0.254	0.020	103.	95.	3.5
6	2	0.253	0.020	106.	93.	5.0
7	37	0.252	0.020	101.	92.	2.0
7	38	0.252	0.020	96.	89.	4.0
7	39	0.252	0.020	107.	94.	5.0
8	15	0.253	0.020	103.	95.	5.0
8	16	0.253	0.020	104.	94.	5.0
10	17	0.253	0.020	107.	88.	7.0
14	21	0.256	0.021	128.	114.	3.0
14	22	0.256	0.022	118.	102.	4.0
14	23	0.254	0.020	128.	108.	2.5
14	24	0.254	0.020	111.	99.	3.0
14	58	0.255	0.021	119.	103.	4.0
14	59	0.255	0.021	118.	104.	4.0
14	6	0.255	0.020	117.	102.	4.0
14	61	0.254	0.021	113.	98.	4.5
14	62	0.254	0.020	111.	96.	6.5
14	63	0.254	0.020	116.	102.	3.5

TABLE B-9. R512E/CB752, WELDED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
16	1	0.251	0.020	235.	182.	13.0
16	2	0.252	0.020	243.	190.	15.5
16	3	0.252	0.021	239.	182.	16.0
16	4	0.252	0.020	242.	188.	17.0
15	5	0.252	0.020	237.	186.	17.0
16	6	0.251	0.020	238.	187.	14.5
16	7	0.251	0.019	235.	184.	13.0
16	8	0.252	0.020	238.	187.	16.0
15	1	0.252	0.020	237.	185.	13.0
15	2	0.253	0.020	238.	185.	9.5(a)

(a) This specimen failed in a brittle mode through the weld metal as opposed to others in this group which failed in a ductile mode in the base metal. No welding defect or contamination could be found, so this value was accepted as valid.

TABLE B-10. R512E/CB752, WELDED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
15	13	0.253	0.020	153.	109.	7.0
15	14	0.252	0.020	165.	112.	7.0
16	17	0.253	0.020	153.	115.	4.0
16	18	0.252	0.020	153.	115.	5.0
16	19	0.251	0.020	150.	116.	3.0
16	20	0.252	0.020	153.	121.	6.0
16	21	0.253	0.020	158.	111.	8.0
16	22	0.253	0.020	151.	107.	6.0
16	23	0.252	0.020	153.	110.	6.0
16	24	0.253	0.021	158.	110.	7.0

TABLE B-11. R512E/CB752, WELDED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
15	3	0.253	0.020	129.	107.	2.5
15	4	0.253	0.020	125.	107.	3.0
16	9	0.252	0.020	126.	108.	3.0
16	1	0.252	0.020	132.	108.	4.0
16	11	0.252	0.020	128.	107.	1.0
16	12	0.252	0.021	125.	107.	3.0
16	13	0.252	0.020	128.	108.	3.0
16	14	0.252	0.020	128.	110.	3.0
16	15	0.252	0.020	129.	108.	3.0
16	16	0.252	0.020	129.	109.	1.5

TABLE B-12. R512E/CB752, WELDED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
15	5	0.253	0.020	111.	107.	2.0
15	6	0.252	0.020	111.	108.	2.5
16	57	0.253	0.020	115.	109.	2.0
16	58	0.252	0.020	115.	110.	3.0
16	59	0.252	0.020	115.	110.	3.0
16	60	0.253	0.021	115.	108.	2.0
16	61	0.253	0.021	108.	106.	2.0
16	62	0.252	0.020	111.	103.	2.0
16	63	0.252	0.020	111.	110.	3.0
16	64	0.252	0.020	113.	110.	2.0

TABLE B-13. R512E/CB752, WELDED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION,(a) PERCENT
15	7	0.253	0.020	109.	107.	0.0
15	8	0.252	0.020	106.(b)	-0.	0.0
16	49	0.252	0.020	112.	111.	0.0
16	50	0.252	0.020	105.(b)	-0.	0.0
16	51	0.252	0.020	112.	110.	0.0
16	52	0.252	0.020	113.	108.	1.0
16	53	0.253	0.020	113.	111.	2.0
16	54	0.253	0.021	113.	111.	1.0
16	55	0.252	0.020	105.(b)	-0.	0.0
16	56	0.252	0.020	114.	112.	1.0

(a) Elongations that are zero were too small to measure.

(b) Specimen did not reach .2% offset.

TABLE B-14. R512E/CB752, WELDED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
15	9	0.253	0.020	115.	113.	2.0
15	1	0.252	0.020	111.	110.	2.0
16	41	0.252	0.020	109.	108.	2.0
16	42	0.253	0.020	109.	107.	2.0
16	43	0.252	0.020	111.	105.	2.0
16	44	0.252	0.020	114.	108.	1.0
16	45	0.252	0.020	111.	108.	2.0
16	47	0.253	0.020	111.	107.	1.0
16	48	0.252	0.021	114.	111.	2.0

TABLE B-15. R512E/CB752, WELDED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
15	11	0.251	0.020	111.	93.	3.0
15	12	0.253	0.020	109.	100.	3.0
16	33	0.253	0.020	116.	99.	3.5
16	34	0.253	0.020	112.	101.	4.0
16	35	0.253	0.021	112.	99.	3.0
16	36	0.253	0.020	113.	99.	3.0
16	37	0.253	0.021	113.	98.	2.0
16	38	0.252	0.020	111.	101.	2.5
16	39	0.253	0.020	112.	101.	1.5
16	4	0.253	0.020	107.	97.	1.5

TABLE B-16. R512E/CB752, WELDED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
15	15	0.252	0.020	103.	90.	3.0
16	25	0.253	0.020	102.	92.	3.0
16	26	0.253	0.020	104.	93.	1.0
16	27	0.252	0.020	106.	93.	2.0
16	28	0.253	0.021	100.	83.	2.5
16	29	0.251	0.021	98.	84.	1.5
16	3	0.252	0.021	99.	87.	4.0
16	31	0.252	0.020	100.	87.	2.5
16	32	0.252	0.020	100.	87.	3.0
16	65	0.253	0.020	98.	87.	1.5

TABLE B-17. R512E/CB752, ST/P CYCLED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
6	1	0.252	0.020	256.	213.	16.5
6	2	0.252	0.020	250.	214.	22.0
6	3	0.253	0.020	248.	213.	18.0
5	1	0.252	0.020	242.	208.	17.0
5	2	0.252	0.020	242.	207.	18.0

TABLE B-18. R512E/CB752, ST/P CYCLED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	3	0.253	0.020	149.	116.	6.0
5	4	0.251	0.020	149.	117.	5.0
7	2	0.252	0.021	157.	119.	5.0
7	3	0.253	0.020	157.	119.	7.0
7	4	0.252	0.020	156.	121.	7.0

TABLE B-19. R512E/CB752, ST/P CYCLED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
2	1	0.252	0.021	129.	118.	3.0
2	2	0.251	0.020	122.	114.	3.0
3	1	0.254	0.020	133.	124.	4.0
3	2	0.254	0.020	127.	118.	4.0
4	11	0.255	0.021	132.	119.	3.0

TABLE B-20. R512E/CB752, ST/P CYCLED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
8	1	0.252	0.021	124.	118.	1.0
8	2	0.252	0.020	116.	113.	2.0
8	3	0.252	0.020	113.	112.	1.5
7	1	0.253	0.021	116.	113.	1.0
7	8	0.253	0.021	114.	112.	1.0

TABLE B-21. R512E/CB752, ST/P CYCLED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
11	3	0.254	0.020	116.	108.	4.0
11	4	0.253	0.020	118.	106.	4.0
12	11	0.253	0.020	114.	111.	3.0
12	12	0.254	0.020	116.	108.	2.5
12	14	0.254	0.020	118.	109.	2.5

TABLE B-22. R512E/CB752, ST/P CYCLED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
11	1	0.254	0.020	118.	112.	5.0
11	2	0.253	0.020	115.		2.0
12	13	0.254	0.020	120.	108.	4.0
12	15	0.254	0.020	117.	109.	4.0
12	16	0.254	0.021	122.	113.	3.0

TABLE B-23. R512E/CB752, ST/P CYCLED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	5	0.252	0.020	104.	96.	2.5
5	8	0.253	0.020	112.	102.	3.5
7	5	0.253	0.020	108.	100.	4.0
7	6	0.253	0.020	111.	103.	3.0
7	7	0.253	0.021	107.	98.	4.0

TABLE B-24. R512E/CB752, 5T/P CYCLED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	5	0.252	0.021	100.	95.	2.0
5	7	0.254	0.020	102.	98.	3.0
6	4	0.253	0.020	102.	97.	3.5
6	5	0.252	0.020	100.	93.	3.0
6	6	0.252	0.020	105.	101.	4.0

TABLE B-25. R512E/CB752, 10T/P CYCLED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
2	3	0.252	0.020	247.	212.	16.0
2	4	0.251	0.020	245.	208.	16.0
4	12	0.254	0.020	249.	212.	17.5
3	3	0.254	0.020	248.	211.	16.0
3	4	0.254	0.020	247.	213.	16.0

TABLE B-26. R512E/CB752, 10T/P CYCLED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	9	0.251	0.020	152.	117.	5.0
5	10	0.252	0.020	155.	120.	5.0
7	9	0.253	0.021	116.(a)	115.	2.0
7	1	0.253	0.021	148.	118.	5.0
7	11	0.253	0.021	151.	117.	5.0

(a) Not representative of protected material response under these test conditions. Tentative allowable calculated without this specimen.

TABLE B-27. R512E/CB752, 10T/P CYCLED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
2	5	0.251	0.019	117.	111.	3.0
2	6	0.251	0.020	122.	114.	2.0
3	5	0.254	0.020	128.	120.	3.0
4	13	0.254	0.020	127.	118.	4.0
4	14	0.254	0.020	122.	116.	3.0

TABLE B-28. R512E/CB752, 10T/P CYCLED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
7	12	0.253	0.021	110.	107.	2.0
7	13	0.253	0.020	113.	112.	2.0
8	4	0.252	0.020	121.	118.	1.0
8	5	0.252	0.020	118.	117.	1.5
8	6	0.252	0.020	117.	116.	1.0

TABLE B-29. R512E/CB752, 10T/P CYCLED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
10	5	0.254	0.020	114.	110.	3.0
10	6	0.254	0.020	111.	107.	2.0
12	17	0.254	0.020	116.	113.	1.5
12	18	0.253	0.020	117.	114.	3.0
12	19	0.253	0.020	117.	114.	2.0

TABLE B-30. R512E/CB752, 10T/P CYCLED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
10	7	0.254	0.020	115.	113.	2.0
11	8	0.254	0.020	118.	111.	3.5
12	20	0.253	0.020	116.	112.	2.0
12	21	0.254	0.020	114.	109.	2.5
12	22	0.254	0.020	114.	112.	2.0

TABLE B-31. R512E/CB752, 10T/P CYCLED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	13	0.252	0.020	111.	102.	4.0
5	14	0.251	0.020	112.	103.	3.5
7	14	0.253	0.020	109.	102.	4.5
7	15	0.253	0.020	110.	103.	3.5
7	16	0.252	0.020	112.	106.	3.0

TABLE B-32. R512E/CB752, 10T/P CYCLED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	11	0.252	0.020	98.	88.	3.5
5	12	0.251	0.020	99.	92.	3.0
6	7	0.253	0.020	100.	91.	2.0
6	8	0.253	0.020	101.	91.	3.0
6	9	0.253	0.020	100.	91.	4.0

TABLE B-33. R512E/CB752, 30T/P CYCLED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
2	8	0.252	0.020	236.	201.	10.0
2	9	0.252	0.020	237.	202.	12.0
3	6	0.254	0.021	232.	195.	10.0
4	15	0.254	0.020	235.	198.	12.0
4	16	0.254	0.020	216.(a)	207.	3.0

(a) Typical of coating wearout after 30 T/P cycles.

TABLE B-34. R512E/CB752, 30T/P CYCLED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
5	14	0.251	0.020	117.	109.	2.0
5	22	0.252	0.020	110.	107.	-0.0
12	23	0.253	0.020	108.	106.	2.5
13	24	0.254	0.020	111.		1.5

TABLE B-35. R512E/CB752, 30T/P CYCLED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
6	1	0.253	0.020	123.	111.	2.0
7	25	0.253	0.021	122.	114.	2.0
7	26	0.252	0.020	105.	99.	-0.0
7	27	0.253	0.021	113.	107.	4.0
7	30	0.253	0.021	108.	101.	2.0

TABLE B-36. R512E/CB752, 30T/P CYCLED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
6	11	0.253	0.020	106.	98.	2.5
6	12	0.252	0.020	103.	98.	4.0
7	17	0.253	0.021	93.	89.	2.5
7	18	0.253	0.021	104.	101.	4.0
7	21	0.252	0.020	103.	101.	4.0

TABLE B-37. VH109/C129Y, AS COATED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
22	1	0.254	0.021	273.	222.	19.0
22	2	0.255	0.021	279.	226.	16.0
23	25	0.253	0.021	285.	230.	19.0
23	26	0.253	0.021	282.	232.	17.5
23	27	0.253	0.021	272.	224.	19.0
21	57	0.254	0.020	283.	228.	19.0
20	1	0.255	0.020	303.	243.	17.0
20	2	0.252	0.020	290.	233.	18.0
19	1	0.254	0.020	288.	235.	18.0
19	2	0.254	0.020	287.	232.	16.0
25	1	0.254	0.021	292.	238.	15.0
25	2	0.254	0.021	298.	245.	16.0
25	3	0.255	0.022	293.	242.	19.0
25	4	0.255	0.022	293.	242.	18.0
25	5	0.255	0.022	293.	242.	17.0
25	6	0.256	0.022	297.	246.	17.0
25	7	0.256	0.021	292.	241.	16.0
25	8	0.255	0.021	288.	238.	18.0
25	9	0.256	0.022	293.	242.	17.0
25	10	0.254	0.021	302.	247.	17.0

TABLE B-38. VH109/C129Y, AS COATED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
18	1	0.256	0.021			8.0
18	2	0.254	0.021			5.0
18	3	0.254	0.021			5.0
19	4	0.253	0.020	200.	138.	7.0
19	5	0.256	0.021	210.	140.	8.0
22	3	0.253	0.022	200.	137.	8.0
22	10	0.254	0.021	200.	146.	10.0
23	40	0.256	0.022	198.	137.	10.0
23	41	0.254	0.022	200.	137.	8.0
23	42	0.254	0.021	196.	134.	8.0
24	1	0.254	0.020	206.	146.	10.0
24	2	0.254	0.019	210.	144.	9.0
24	3	0.254	0.019	202.	142.	7.0
25	11	0.255	0.022			9.0
25	12	0.255	0.023			9.0
25(a)	13	0.255	0.021	178.	125.	9.0
25(a)	14	0.254	0.021		129.	9.0
25	15	0.255	0.023			8.0
25(a)	16	0.254	0.021	200.	162.	11.0
25	17	0.254	0.020	236.	143.	7.0

(a) Suspected R.F. interference. Recalculated statistics leaving out these three specimens.

TABLE B-39. VH109/C129Y, AS COATED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
18	4	0.255	0.021	155.	139.	5.0
18	5	0.255	0.021	139.	128.	4.0
18	6	0.254	0.021	143.	130.	4.0
18	7	0.255	0.021	157.	137.	2.0
19	6	0.255	0.020	151.	133.	4.0
22	4	0.255	0.022	146.	131.	5.0
22	9	0.255	0.021	148.	132.	5.0
23	44	0.254	0.022	146.	134.	6.0
23	45	0.254	0.022	148.	132.	6.0
23	46	0.254	0.021	143.	125.	-0.0
24	4	0.254	0.019	157.	135.	6.0
24	5	0.254	0.021	155.	135.	5.0
24	6	0.255	0.020	156.	135.	7.0
24	7	0.255	0.021	152.	133.	8.0
25	18	0.254	0.020	163.	139.	-0.0
25	19	0.254	0.021	154.	131.	5.0
25	20	0.255	0.021	150.	129.	4.0
25	21	0.253	0.021	156.	136.	3.0
25	22	0.255	0.021	160.	135.	6.0
25	23	0.254	0.021	157.	135.	-0.0

TABLE B-40. VH109/C129Y, AS COATED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
18	9	0.255	0.021	149.	139.	3.0
18	10	0.254	0.021	136.	131.	2.0
19	3	0.255	0.021	133.	126.	3.0
19	7	0.255	0.021	133.	131.	2.0
21	98	0.254	0.020	145.	136.	4.0
22	5	0.255	0.021	124.	122.	1.0
23	47	0.254	0.021	133.	128.	3.0
23	48	0.253	0.021	132.	124.	3.0
23	49	0.255	0.021	135.	131.	2.0
23	50	0.254	0.021	132.	128.	3.0
24	8	0.254	0.020	145.	138.	3.0
24	9	0.254	0.021	141.	134.	3.0
24	1	0.254	0.019	144.	137.	4.0
25	24	0.255	0.022	144.	137.	2.0
25	25	0.254	0.021	139.	138.	3.0
25	26	0.254	0.020	141.	135.	2.0
25	27	0.255	0.021	144.	139.	3.0
25	28	0.255	0.021	140.	134.	2.5
25	29	0.254	0.021	145.	138.	2.0
25	30	0.255	0.022	144.	138.	3.5

TABLE B-41. VH109/C129Y, AS COATED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
20	3	0.254	0.020	137.	126.	2.5
20	8	0.256	0.020	133.	123.	2.0
20	10	0.253	0.020	135.	127.	2.0
21	112	0.254	0.020	134.	129.	1.0
21	113	0.254	0.020	138.	130.	2.0
22	6	0.254	0.021	138.	128.	2.0
23	51	0.254	0.022	133.	126.	2.0
23	52	0.252	0.021	135.	131.	1.0
23	53	0.256	0.021	137.	129.	3.0
23	54	0.255	0.020	136.	131.	2.0
25	31	0.254	0.020	147.	135.	2.0
25	32	0.255	0.021	144.	134.	1.0
25	33	0.255	0.022	139.	135.	1.0
25	34	0.255	0.021	139.	132.	1.5
25	35	0.255	0.021	141.	135.	1.5
25	36	0.254	0.021	143.	136.	2.0
25	37	0.254	0.022	148.	138.	1.0
25	38	0.255	0.021	145.	138.	1.0
25	39	0.255	0.021	143.	139.	0.5
25	40	0.254	0.020	152.	140.	1.0

TABLE B-42. VH109/C129Y, AS COATED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
19	9	0.254	0.020	141.	128.	2.0
20	4	0.255	0.019	143.	125.	2.0
20	5	0.255	0.020	142.	130.	1.0
20	6	0.255	0.020	145.	130.	1.0
21	109	0.254	0.020	158.	138.	1.0
23	55	0.254	0.021	135.	122.	2.0
23	56	0.256	0.021	138.	124.	2.0
23	57	0.254	0.021	137.	123.	2.0
23	58	0.254	0.022	138.	127.	3.0
25	41	0.254	0.021	156.	136.	3.0
25	42	0.255	0.022	147.	132.	1.0
25	43	0.255	0.021	154.	138.	2.0
25	44	0.255	0.022	145.	130.	1.0
25	45	0.255	0.021	148.	134.	1.0
25	46	0.255	0.022	146.	132.	1.0
25	47	0.255	0.022	147.	133.	1.0
25	48	0.254	0.021	148.	132.	2.0
25	49	0.254	0.021	149.	134.	2.0
25	50	0.254	0.021	153.	139.	2.0

TABLE B-43. VH109/C129Y, AS COATED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
19	1[illegible]	0.255	0.020	146.	118.	3.0
20	7	0.254	0.020	143.	123.	3.5
20	8	0.255	0.021	142.	120.	3.5
20	9	0.252	0.020	142.	123.	4.5
21	11[illegible]	0.255	0.021	141.	127.	3.0
22	8	0.255	0.021	134.	120.	3.0
23	59	0.253	0.020	132.	113.	4.0
23	60	0.255	0.020	135.	117.	3.0
23	61	0.253	0.021	136.	123.	2.5
23	62	0.255	0.020	142.	123.	2.5
25	51	0.255	0.022	147.	125.	3.5
25	52	0.254	0.021	145.	126.	3.0
25	53	0.254	0.021	149.	128.	3.0
25	54	0.254	0.021	148.	128.	3.0
25	55	0.254	0.021	148.	127.	3.5
25	56	0.254	0.021	143.	122.	4.0
25	57	0.254	0.020	141.	122.	3.0
25	58	0.255	0.021	140.	126.	4.0
25	59	0.254	0.020	142.	123.	3.0
25	60	0.255	0.021	141.	123.	4.0

TABLE B-44. VH109/C129Y, AS COATED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	114	0.256	0.021	121.	110.	2.5
21	116	0.254	0.020	122.	109.	2.5
21	117	0.255	0.020	123.	109.	2.5
21	118	0.255	0.020	120.	108.	1.5
21	119	0.255	0.020	117.	108.	3.0
23	43	0.255	0.021	112.	104.	1.5
23	63	0.254	0.020	112.	102.	2.0
23	64	0.254	0.021	114.	105.	2.5
23	65	0.253	0.020	113.	105.	2.0
23	66	0.254	0.020	111.	103.	2.0
23	67	0.254	0.021	118.	107.	1.5
25	61	0.255	0.022	118.	110.	2.5
25	62	0.256	0.023	127.	111.	2.5
25	63	0.255	0.022	120.	108.	3.0
25	64	0.256	0.022	118.	108.	1.5
25	65	0.254	0.022	124.	110.	3.0
25	66	0.255	0.022	119.	111.	1.5
25	67	0.255	0.023	118.	106.	4.0
25	68	0.255	0.020	123.	109.	2.0
25	69	0.255	0.021	126.	113.	3.0

TABLE B-45. VH109/C129Y, WELDED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
27(a)	1	0.255	0.021	290.	238.	19.0
27	2	0.253	0.020	258.	213.	10.0
27	3	0.254	0.020	232.	204.	5.0
27	4	0.252	0.020	250.	207.	10.0
27	5	0.253	0.021	250.	211.	7.5
27	6	0.253	0.020	250.	207.	10.0
27	7	0.255	0.021	248.	207.	8.0
27	8	0.254	0.021	249.	208.	9.0
26	1	0.253	0.020	259.	220.	7.5
26	2	0.254	0.020	258.	220.	7.5

(a) Metallography showed no weld. There was a single sample mix-up known to have occurred during coating. Group recalculated leaving out this specimen.

TABLE B-46. VH109/C129Y, WELDED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
26	11	0.253	0.019	172.	127.	6.0
26	12	0.253	0.019	173.	127.	8.0
27	9	0.255	0.021	185.	137.	6.0
27	1	0.253	0.020	185.	124.	8.0
27	11	0.254	0.020	174.	125.	0.0
27	12	0.253	0.020	186.	128.	6.0
27	13	0.254	0.021	184.	126.	8.0
27	14	0.253	0.021	172.	127.	8.0
27	15	0.253	0.021	178.	123.	8.0
27	16	0.254	0.020	185.	123.	8.0

TABLE B-47. VH109/C129Y, WELDED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
26	3	0.253	0.020	153.	125.	5.0
26	4	0.255	0.020	147.	125.	4.0
27	17	0.254	0.020	149.	128.	4.0
27	18	0.254	0.021	157.	127.	5.0
27	19	0.254	0.021	125.(a)	93.(a)	5.0
27	2	0.253	0.020	154.	127.	2.0
27	21	0.253	0.020	162.	131.	4.5
27	22	0.254	0.020	157.	131.	2.5
27	23	0.253	0.020	148.	124.	2.5
27	24	0.254	0.020	151.	123.	3.0

(a) Metallography showed some uneveness of coating causing smaller substrate but not enough to account for the difference. Reason for this low yield and ultimate strength, unknown.

TABLE B-48. VH109/C129Y, WELDED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
26	5	0.254	0.021	136.	130.	2.5
26	6	0.253	0.020	134.	128.	2.0
27	25	0.254	0.020	130.	127.	3.0
27	26	0.253	0.020	127.	126.	2.5
27	27	0.254	0.020	128.	125.	2.5
27	28	0.254	0.020	108.(a)	101.(a)	2.0
27	29	0.256	0.021	128.	123.	2.0
27	30	0.254	0.021	135.	127.	2.0
27	31	0.252	0.020	128.	122.	3.0
27	32	0.253	0.020	128.	124.	2.0

(a) More substrate consumed than expected. Assumed to be coating variability extreme.

TABLE B-49. VH109/C129Y, WELDED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
26	7	0.253	0.020	128.	125.	1.0
26	8	0.253	0.019	132.	126.	2.0
27	33	0.253	0.020	123.	121.	1.0
27	34	0.254	0.022	125.	124.	1.0
27	35	0.254	0.021	130.	124.	2.0
27	36	0.253	0.021	124.	121.	2.0
27	37	0.255	0.021	124.	122.	2.0
27	38	0.254	0.021	125.	117.	1.5
27	39	0.253	0.021	128.	127.	2.0
27	40	0.254	0.021	132.	127.	2.0

TABLE B-50. VH109/C129Y, WELDED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
26	9	0.252	0.019	129.	125.	3.0
26	1	0.254	0.019	130.	121.	3.0
27	41	0.253	0.021	133.	125.	3.0
27	42	0.254	0.021	124.	117.	2.0
27	43	0.256	0.022	126.	118.	1.0
27	44	0.255	0.021	136.	124.	3.0
27	45	0.255	0.021	130.	123.	1.0
27	46	0.254	0.020	130.	124.	1.0
27	48	0.253	0.021	128.	123.	3.0

TABLE B-51. VH109/C129Y, WELDED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
26	13	0.254	0.020	129.	118.	2.5
26	14	0.253	0.020	130.	116.	2.0
27	49	0.255	0.021	125.	116.	3.0
27	5	0.254	0.022	141.	125.	3.0
27	51	0.255	0.021	123.	118.	2.5
27	52	0.254	0.021	122.	114.	3.0
27	53	0.255	0.021	125.	118.	2.5
27	54	0.255	0.021	118.	109.	2.5
27	55	0.254	0.021	128.	118.	3.5
27	56	0.255	0.020	130.	122.	2.5

TABLE B-52. VH109/C129Y, WELDED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
26	15	0.253	0.020	106.	99.	5.0
27	57	0.255	0.020	99.	94.	3.0
27	59	0.256	0.021	107.	101.	3.0
27	60	0.255	0.021	104.	98.	1.5
27	61	0.255	0.021	103.	95.	2.5
27	62	0.254	0.021	97.	91.	3.0
27	63	0.255	0.021	103.	98.	2.0
27	64	0.255	0.021	109.	100.	3.0
27	65	0.254	0.021	108.	99.	3.0
27	66	0.254	0.021	104.	98.	2.0

TABLE B-53. VH109/C129Y, ST/P CYCLED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	2	0.255	0.021	279.	230.	19.0
21	3	0.255	0.021	277.	228.	17.0
21	4	0.255	0.020	279.	229.	15.0
23	2	0.255	0.022	271.	223.	18.0
23	1	0.253	0.022	268.	221.	17.0

TABLE B-54. VH109/C129Y, ST/P CYCLED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	5	0.252	0.020	206.	148.	8.0
21	7	0.255	0.020	191.	141.	8.0
21	8	0.255	0.020	200.	142.	9.0
21	13	0.254	0.020	196.	142.	6.0
23	3	0.253	0.021	194.	141.	8.0

TABLE B-55. VH109/C129Y, ST/P CYCLED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	1	0.255	0.022	164.	141.	4.0
21	6	0.255	0.020	152.	132.	3.0
21	9	0.253	0.019	153.	131.	3.0
23	21	0.253	0.021	148.	130.	3.0
23	22	0.255	0.021	149.	132.	2.5

TABLE B-56. VH109/C129Y, ST/P CYCLED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	1	0.255	0.020	141.	132.	1.0
21	11	0.254	0.020	143.	136.	2.0
21	12	0.254	0.021	147.	135.	2.0
23	4	0.253	0.021	134.	126.	2.0
23	23	0.253	0.021	138.	131.	2.0

TABLE B-57. VH109/C129Y, ST/P CYCLED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	19	0.254	0.020	143.	133.	1.0
21	2	0.254	0.020	143.	132.	1.0
21	22	0.255	0.020	140.	131.	1.0
23	5	0.253	0.020	137.	131.	1.0
23	6	0.254	0.022	138.	126.	2.0

TABLE B-58. VH109/C129Y, ST/P CYCLED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	21	0.257	0.020	143.	132.	3.0
21	23	0.256	0.021	153.	138.	4.0
21	27	0.255	0.020	141.	126.	3.0
23	7	0.254	0.022	141.	132.	4.0
23	8	0.253	0.021	141.	131.	2.5

TABLE B-59. VH109/C129Y, ST/P CYCLED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	24	0.256	0.020	130.	118.	4.0
21	25	0.254	0.020	133.	119.	3.0
21	26	0.254	0.020	128.	117.	3.5
21	28	0.254	0.020	130.	116.	2.5
23	9	0.253	0.021	124.	116.	3.5

TABLE B-60. VH109/C129Y, ST/P CYCLED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	14	0.255	0.020	116.	102.	4.0
21	15	0.255	0.020	110.	101.	3.0
21	16	0.255	0.020	105.	97.	3.5
21	17	0.255	0.020	111.	101.	3.0
21	18	0.255	0.020	116.	107.	2.0

TABLE B-61. VH109/C129Y, 10T/P CYCLED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
23	16	0.254	0.021	268.	223.	16.0
23	17	0.252	0.021	263.	220.	17.0
21	29	0.255	0.020	280.	229.	17.0
21	30	0.255	0.020	280. (a)	228. (a)	16.0
21	31	0.253	0.020	293.	243.	16.0

(a) Metallography showed less substrate consumed than expected. Specimen considered as coating variability extreme.

TABLE B-62. VH109/C129Y, 10T/P CYCLED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	50	0.255	0.020	196.	143.	7.0
21	51	0.255	0.021	209.	148.	6.0
21	56	0.254	0.020	196.	140.	6.0
23	1	0.254	0.021	185.	132.	7.0
23	11	0.253	0.021	186.	137.	6.0

TABLE B-63. VH109/C129Y, 10T/P CYCLED, 1300 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	43	0.255	0.019	148.	137.	1.0
21	44	0.255	0.021	173.	148.	5.0
21	45	0.255	0.020	163.	140.	4.0
21	46	0.255	0.021	159.	139.	3.0
23	2	0.252	0.021	146.	137.	3.0

TABLE B-64. VH109/C129Y, 10T/P CYCLED, 1600 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	36	0.256	0.020	133.	132.	0.0
21	47	0.255	0.021	147.	140.	1.0
21	48	0.255	0.021	143.	136.	2.0
23	19	0.255	0.022	134.	129.	2.0
23	24	0.255	0.022	131.	124.	1.0

TABLE B-65. VH109/C129Y, 10T/P CYCLED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	37	0.254	0.020	136.	125.	1.0
21	38	0.256	0.021	129.	126.	2.0
21	49	0.254	0.020	134.	125.	1.0
23	12	0.253	0.021	139.	130.	1.0
23	13	0.256	0.021	126.	122.	1.0

TABLE B-66. VH109/C129Y, 10T/P CYCLED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	52	0.255	0.021	138.	128.	3.5
21	53	0.256	0.020	137.	128.	3.0
21	54	0.255	0.020	138.	131.	2.5
21	55	0.252	0.020	136.	129.	2.0
23	14	0.252	0.021	128.	123.	3.0

TABLE B-67. VH109/C129Y, 10T/P CYCLED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	39	0.255	0.021	122.	100.	4.0
21	4	0.255	0.020	131.	119.	3.0
21	41	0.253	0.020	132.	118.	2.0
21	42	0.258	0.020	127.	117.	2.5
23	15	0.253	0.021	125.	118.	2.5

TABLE B-68. VH109/C129Y, 10T/P CYCLED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	DIMENSIONS, INCH THICKNESS	LOADS, LBS ULTIMATE	LOADS, LBS YIELD	ELONGATION, PERCENT
21	32	0.256	0.020	111.	103.	3.5
21	33	0.253	0.021	104.	96.	2.0
21	34	0.255	0.020	109.	101.	3.5
21	35	0.254	0.021	105.	96.	3.0
23	18	0.254	0.022	106.	103.	2.5

TABLE B-69. VH109/C129Y, 30T/P CYCLED, 80 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	59	0.255	0.021	286.	228.	17.0
21	6	0.254	0.019	267.	218.	15.0
21	61	0.254	0.020	282.	228.	14.0
23	28	0.253	0.021	262.	189.	13.0
23	29	0.255	0.021	237.	196.	14.0

TABLE B-70. VH109/C129Y, 30T/P CYCLED, 1000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	69	0.255	0.020	207.	148.	2.0
21	77	0.256	0.022	191.	141.	5.0
21	78	0.254	0.020	200.	142.	4.0
23	34	0.254	0.020	196.	142.	3.0
23	35	0.254	0.021	194.	142.	3.0

TABLE B-71. VH109/C129Y, 30T/P CYCLED, 1800 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	71	0.255	0.020	139.	127.	3.0
21	72	0.255	0.020	136.	126.	2.0
21	74	0.255	0.019	138.	129.	3.5
21	75	0.253	0.020	141.	124.	4.0
21	76	0.255	0.020	141.	131.	3.5

TABLE B-72. VH109/C129Y, 30T/P CYCLED, 2000 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	65	0.255	0.020	125.	114.	2.5
21	66	0.254	0.019	134.	118.	3.5
21	67	0.255	0.019	142.	127.	2.5
21	68	0.255	0.020	137.	118.	3.0
21	7	0.253	0.020	128.	116.	2.0

TABLE B-73. VH109/C129Y, 30T/P CYCLED, 2200 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	64	0.255	0.020	118.	108.	2.5
23	36	0.254	0.020	118.	101.	2.5
23	37	0.254	0.021	118.	105.	3.0
23	38	0.255	0.022	115.	104.	4.5
23	39	0.254	0.021	114.	99.	4.0

TABLE B-74. VH109/C129Y, 30T/P CYCLED, 2400 F

GROUP NUMBER	SPECIMEN NUMBER	DIMENSIONS, INCH WIDTH	THICKNESS	LOADS, LBS ULTIMATE	YIELD	ELONGATION, PERCENT
21	83	0.255	0.020	115.	112.	2.0
21	84	0.255	0.021	117.	111.	2.0
21	85	0.254	0.020	119.	116.	1.5
23	31	0.254	0.021	107.	103.	3.0
23	32	0.255	0.021	113.	108.	4.0

APPENDIX C

TENSILE TEST DATA AND DESIGN ALLOWABLES CALCULATIONS

APPENDIX C

TENSILE TEST DATA AND DESIGN ALLOWABLES CALCULATIONS

The tables in Appendix C are in two parts. On the left side of the page are listed the computed tensile ultimate strength, tensile yield strength, and elongation values for individual specimens for each set of data. The strength computations are obtained from the load values shown in corresponding tables in Appendix B and are based on the uncoated specimen dimensions.

The right side of each table in Appendix C is a summary of the computations that were conducted for each set of data. The printout shows the number of data points, the average value, the standard deviation, a specimen tally by deciles under the normal curve, the chi-squared tests for normality, and the A and B allowables.

The sets of data are defined by the coating/alloy system, the material condition parameter, and the test temperature. Eight tables are available for each coating/alloy system and material condition parameter except for the 30 T/P test condition as explained in the text. These eight tables are presented in ascending order of test temperature. To provide some facility in locating the specific tables, the following tabulation can be referred to:

R512E/Cb752	
As coated	Tables C-1 – C-8
Welded and coated	Tables C-9 – C-16
As coated, 5 T/P cycles	Tables C-17 – C-24
As coated, 10 T/P cycles	Tables C-25 – C-32
As coated, 30 T/P cycles	Tables C-33 – C-36
VH109/C129Y	
As coated	Tables C-37 – C-44
Welded and coated	Tables C-45 – C-52
As coated, 5 T/P cycles	Tables C-53 – C-60
As coated, 10 T/P cycles	Tables C-61 – C-68
As coated, 30 T/P cycles	Tables C-69 – C-74.

TABLE C-1. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
54.67	73.33	17.00
54.13	71.20	17.00
56.80	74.13	14.00
56.00	73.33	17.00
55.20	72.53	16.00
56.80	73.60	18.00
54.93	71.73	17.00
54.93	72.00	15.00
55.47	72.80	18.00
56.53	73.33	17.00
53.87	68.27	19.00
52.48	65.86	20.00
53.55	66.93	20.00
54.89	68.54	19.00
53.55	67.47	18.00
54.89	68.01	19.00
53.01	66.40	16.00
53.55	68.27	20.00
53.55	68.27	17.00
51.73	65.60	19.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	20
AVERAGE	54.53	70.08	1.24*
STD. DEV.	1.394	2.957	0.042*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	2	2	2
	1	3	2
	4	4	0
	2	1	6
	0	0	0
	1	0	3
	5	1	0
	1	3	4
	1	5	0
	3	1	3
CHI SQUARED	11.00	13.00	19.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	49.92	60.34	12.6[a]
B BASIS	51.83	64.38	

(a) Calculated assuming normality.

TABLE C-2. STRENGTH DATA FOR R512E/Cb752, AS COATED AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
30.13	39.47	5.00
32.53	39.47	4.00
31.20	38.13	4.00
32.80	41.33	5.00
30.13	36.80	5.00
30.67	38.13	4.00
30.79	38.29	5.00
29.94	38.82	7.00
30.79	37.22	4.00
32.13	42.30	7.00
31.06	38.29	4.00
32.13	40.70	4.00
31.73	42.93	6.00
31.47	42.93	4.00
31.47	40.53	4.00
33.07	43.73	5.00
32.53	42.13	4.00
33.07	42.67	5.00
32.80	43.20	6.00
34.93	43.20	5.00
31.20	40.00	4.00
33.33	44.53	4.50
31.20	42.13	5.00
31.20	41.60	5.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	24	24	24
AVERAGE	31.76	40.77	0.68*
STD. DEV.	1.194	2.257	0.077*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	3	2	0
	1	5	10
	3	2	0
	4	1	1
	3	2	0
	0	1	0
	2	1	9
	2	4	0
	4	4	0
	2	2	4
CHI SQUARED	6.00	7.67	58.50
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	27.82	33.34	2.7[a]
B BASIS	29.46	36.43	

(a) Calculated assuming normality.

TABLE C-3. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT 1300 F
(BASED ON UNCOATED SPECIMENS DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
31.20	37.07	3.00
29.60	34.93	3.50
31.20	36.53	1.50
29.07	33.33	3.50
29.60	33.87	3.00
29.07	34.67	3.50
28.53	33.33	2.00
28.80	34.13	2.00
29.60	35.73	3.00
29.33	34.13	4.00
31.20	36.80	1.00
31.20	36.80	1.00
31.20	37.33	2.00
31.47	38.40	3.00
31.47	37.33	2.00
31.47	36.80	2.00
31.47	37.07	4.00
31.47	38.40	3.00
30.67	36.27	1.00
30.67	36.53	2.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	20	20	20
AVERAGE	30.41	35.97	0.36*
STD. DEV.	1.059	1.602	0.196*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	2	3	3
	3	2	1
	3	2	0
	0	0	6
	0	1	0
	2	1	0
	0	5	0
	5	2	5
	5	2	5
	0	2	0
CHI SQUARED	18.00	8.00	28.00
NORMAL	NO	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	26.9(a)	30.70	0.5(a)
B BASIS	28.3(a)	32.89	

(a) Calculated assuming normality.

TABLE C-4. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT 1600 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
29.60	35.40	2.00
29.60	31.47	3.00
31.20	32.27	2.50
31.47	32.53	2.00
29.87	31.20	2.00
28.65	29.72	2.00
29.60	30.67	2.50
28.80	30.13	3.00
29.60	30.40	2.00
29.07	29.33	2.00
30.13	31.20	2.00
33.07	33.87	2.00
33.07	33.87	3.00
32.85	33.33	3.00
36.00	37.33	3.00
33.60	33.60	1.00
33.07	33.33	3.00
33.87	34.67	1.00
32.27	32.27	2.00
32.27	32.80	1.50
31.47	32.27	2.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	21	21	21
AVERAGE	31.36	32.22	0.33*
STD. DEV.	2.004	1.911	0.139*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	2	2	2
	5	3	1
	2	3	0
	0	1	0
	1	0	10
	2	4	0
	2	1	2
	4	3	0
	2	3	6
	1	1	0
CHI SQUARED	9.00	7.19	48.05
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	24.77	25.93	0.8(a)
B BASIS	27.52	28.54	

(a) Calculated assuming normality.

TABLE C-5. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
30.67	31.20	1.00
33.60	34.40	1.00
29.33	30.13	2.00
31.47	32.80	1.00
30.13	32.27	0.00
30.13	30.93	2.00
28.80	30.13	2.00
30.67	31.47	1.00
29.33	30.67	2.00
30.13	30.67	2.00
28.80	29.87	1.00
32.00	33.07	1.00
34.40	36.27	2.00
31.73	33.33	2.00
30.67	33.60	1.00
30.67	33.60	2.00
32.53	33.87	1.50
32.27	33.60	1.00
32.50	33.87	00.50
32.53	34.13	1.00
33.60	34.93	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	21	21	20
AVERAGE	31.25	32.61	00.13*
STD. DEV.	1.628	1.799	00.178*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

2	3	1
2	3	0
3	2	9
4	0	0
0	1	0
1	1	0
2	2	1
3	5	0
1	2	9
3	2	0

	TYS	TUS	ELONG.
CHI SQUARED	6.14	8.05	62.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	25.89	26.68	0.3[a]
B BASIS	28.11	29.14	

(a) Calculated assuming normality.

TABLE C-6. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.53	29.60	2.50
30.25	31.33	2.50
29.18	30.52	2.50
29.72	31.59	3.00
29.18	30.79	3.00
30.52	32.40	2.00
30.79	32.40	2.00
30.79	32.66	3.00
30.52	32.66	3.00
29.07	30.40	3.00
34.13	35.20	2.00
33.60	34.67	4.00
0.00	31.20	4.00
33.60	35.73	3.00
32.80	34.40	2.00
33.87	34.40	2.00
32.80	33.60	2.00
32.53	33.87	2.50
32.53	33.87	2.50
33.33	34.40	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	19	20	20
AVERAGE	31.46	32.78	00.42*
STD. DEV.	1.876	1.789	00.096*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

1	2	0
4	3	6
1	2	0
4	0	0
0	4	5
0	0	0
0	1	0
4	2	7
3	4	0
2	2	2

	TYS	TUS	ELONG.
CHI SQUARED	14.16	9.00	37.00
NORMAL	NO	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	25.2[a]	26.92	1.3[a]
B BASIS	27.8[a]	29.36	

(a) Calculated assuming normality.

TABLE C-7. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
25.87	29.87	4.00
26.40	30.67	4.50
26.13	30.40	4.00
26.24	30.79	3.50
25.97	29.72	4.00
25.87	30.40	4.50
24.00	28.53	3.50
25.60	30.40	3.50
26.13	31.20	4.50
25.47	31.20	3.00
29.33	34.93	3.50
29.60	35.27	4.50
29.33	36.53	3.50
29.87	35.20	4.00
29.87	35.47	3.00
30.40	36.00	3.00
29.60	36.00	4.00
29.60	36.00	3.50
29.87	36.80	3.00
30.13	36.00	4.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	20
AVERAGE	27.78	33.12	00.57*
STD. DEV.	2.093	2.952	00.062*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	4
	5	5	0
	4	4	0
	0	0	6
	0	0	0
	0	0	0
	0	0	6
	2	3	0
	8	7	0
	0	0	4
CHI SQUARED	35.00	30.00	32.00
NORMAL	NO	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	20.9(a)	23.4(a)	1.8(a)
B BASIS	23.7(a)	27.4(a)	

(a) Calculated assuming normality.

TABLE C-8. STRENGTH DATA FOR R512E/Cb752, AS COATED, AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
24.80	27.73	5.00
24.90	25.70	3.00
25.44	27.58	3.50
24.90	28.38	5.00
24.63	27.04	2.00
23.93	25.70	4.00
25.17	28.65	5.00
25.44	27.58	5.00
25.17	27.84	5.00
23.47	28.53	7.00
30.40	34.13	3.00
27.20	31.47	4.00
28.80	34.13	2.50
26.40	29.60	3.00
27.47	31.73	4.00
27.73	31.47	4.00
27.20	31.20	4.00
26.13	30.13	4.50
25.60	29.60	6.50
27.20	30.93	3.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	20
AVERAGE	26.09	29.46	00.60*
STD. DEV.	1.712	2.428	00.134*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	2	2	2
	1	1	3
	5	4	0
	3	3	2
	0	0	0
	2	2	5
	0	1	1
	4	4	5
	1	1	0
	2	2	2
CHI SQUARED	12.00	8.00	16.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	20.45	21.45	1.4(a)
B BASIS	22.80	24.78	

(a) Calculated assuming normality.

TABLE C-9. STRENGTH DATA ON R512E/Cb752, WELDED, AT ROOM TEMPERATURE
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
49.12	63.43	13.00
51.28	65.59	15.50
49.12	64.51	16.00
50.74	65.32	17.00
51.20	63.97	17.00
50.47	64.24	14.50
49.66	63.43	13.00
53.47	64.24	16.00
49.93	63.97	13.00
49.93	64.24	9.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	50.09	64.29	1.15*
STD. DEV.	00.688	00.706	00.077*
(* = LOG BASE 10)			
TALLY BY DECILES UNDER THE NORMAL CURVE			
	2	0	1
	0	2	0
	1	0	0
	0	2	3
	2	3	0
	1	0	1
	0	1	1
	2	0	2
	1	0	2
	1	2	0
CHI SQUARED	6.00	12.00	10.00
NORMAL	YES	YES	YES
MIL-HDBK-5 A + B VALUES			
A BASIS	47.35	61.48	7.01
B BASIS	48.47	62.63	

TABLE C-10. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 1000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
29.42	41.30	7.00
30.23	44.53	7.00
31.04	41.30	4.00
31.04	41.30	5.00
31.31	40.49	3.00
32.66	41.30	6.00
29.96	42.65	8.00
28.86	40.76	6.00
29.69	41.30	6.00
29.69	42.65	7.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	30.39	41.76	00.76*
STD. DEV.	1.118	1.199	00.130*
(* = LOG BASE 10)			
TALLY BY DECILES UNDER THE NORMAL CURVE			
	1	0	1
	1	1	1
	2	1	0
	1	5	1
	1	0	0
	0	0	3
	0	0	0
	3	2	3
	0	0	1
	1	1	0
CHI SQUARED	8.00	22.00	12.00
NORMAL	YES	NO	YES
MIL-HDBK-5 A + B VALUES			
A BASIS	25.94	37.0(a)	1.73
B BASIS	27.76	38.9(a)	2.81

(a) Calculated assuming normality.

TABLE C-11. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 1300 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.88	34.82	2.50
28.88	33.74	3.00
29.15	34.01	3.00
29.15	35.63	4.00
28.88	34.55	1.00
28.88	33.74	3.00
29.15	34.55	3.00
29.69	34.55	3.00
29.15	34.82	3.00
29.42	34.82	1.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	29.12	34.52	00.40*
STD. DEV.	00.258	00.576	00.178*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	2	1
	4	1	1
	0	0	0
	0	0	0
	0	0	1
	4	3	0
	0	3	6
	0	0	0
	1	0	1
	1	1	0
CHI SQUARED	24.00	14.00	30.00
NORMAL	NO	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	28.0(a)	32.23	0.5(a)
B BASIS	28.5(a)	33.17	

(a) Calculated assuming normality.

TABLE C-12. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 1600 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.86	29.96	2.00
29.15	29.96	2.50
29.42	31.04	2.00
29.69	31.04	3.00
29.69	31.04	3.00
29.15	31.04	2.00
28.61	29.15	2.00
27.80	29.96	2.00
29.69	29.96	3.00
29.69	30.50	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	29.18	30.36	00.36*
STD. DEV.	00.616	00.664	00.084*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	0
	1	0	0
	0	4	6
	1	0	0
	2	0	0
	0	1	0
	1	0	1
	4	0	0
	0	4	0
	0	0	3
CHI SQUARED	14.00	24.00	36.00
NORMAL	YES	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	26.72	27.7(a)	1.0(a)
B BASIS	27.73	28.8(a)	

(a) Calculated assuming normality.

TABLE C-13. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.88	29.42	0.00
0.00	28.61	0.00
29.96	30.23	0.00
0.00	28.34	0.00
29.69	30.23	0.00
29.15	30.50	1.00
29.96	30.50	2.00
29.96	30.50	1.00
0.00	28.34	0.00
30.23	30.77	1.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	7	10	4
AVERAGE	29.69	29.74	00.08*
STD. DEV.	00.493	00.976	00.151*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	2	0
	1	1	0
	0	0	0
	0	1	3
	0	0	0
	1	0	0
	0	2	0
	3	3	0
	1	1	0
	0	0	1
CHI SQUARED	11.57	10.00	21.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	26.86	25.86	0.1(a)
B BASIS	28.01	27.45	

(a) Calculated assuming normality.

TABLE C-14. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
30.50	31.04	2.00
29.69	29.96	2.00
29.15	29.42	2.00
28.88	29.42	2.00
28.34	29.96	2.00
29.15	30.77	1.00
29.15	29.96	2.00
28.88	29.96	1.00
29.96	30.77	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	9	9	9
AVERAGE	29.30	30.14	00.23*
STD. DEV.	00.649	00.588	00.134*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	0	2
	0	2	0
	2	0	0
	0	4	0
	3	0	0
	0	0	0
	0	0	7
	1	0	0
	1	2	0
	1	1	0
CHI SQUARED	9.89	18.78	49.89
NORMAL	YES	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	25.57	27.7(a)	0.4(a)
B BASIS	27.09	28.7(a)	

(a) Calculated assuming normality.

TABLE C-15. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
25.10	29.96	3.00
26.99	29.42	3.00
25.72	29.69	3.50
27.26	30.23	4.00
26.72	30.23	3.00
26.72	30.50	3.00
26.45	30.50	2.00
27.26	29.96	2.50
27.26	30.23	1.50
26.18	28.88	1.50

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	10	10	10
AVERAGE	26.67	29.96	00.41*
STD. DEV.	00.659	00.509	00.147*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	1	1	2
	0	1	0
	1	1	1
	1	0	0
	0	0	1
	3	2	0
	1	0	4
	0	3	0
	3	2	1
	0	0	1
CHI SQUARED	12.00	10.00	14.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	24.64	27.93	00.67
B BASIS	25.11	28.76	

TABLE C-16. STRENGTH DATA FOR R512E/Cb752, WELDED, AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
24.29	27.80	3.00
24.83	27.53	3.00
25.10	28.07	1.00
25.10	28.61	2.00
22.40	26.99	2.50
22.67	25.45	1.50
23.48	26.72	4.00
23.48	26.99	2.50
23.48	26.99	3.00
23.48	25.45	1.50

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	10	10	10
AVERAGE	23.83	27.26	00.35*
STD. DEV.	00.961	00.72	00.183*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	1	0	1
	1	2	2
	0	1	0
	4	3	1
	0	0	0
	0	0	0
	1	1	2
	0	1	3
	1	1	0
	2	1	1
CHI SQUARED	14.00	8.00	10.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	20.00	24.39	00.42
B BASIS	21.57	25.56	

TABLE C-17. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
57.03	66.93	16.50
57.30	66.93	22.00
57.03	65.40	18.00
55.69	64.79	17.00
55.42	64.79	18.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	56.49	65.97	1.26*
STD. DEV.	00.869	1.097	00.049*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG..
	0	0	0
	2	2	1
	0	0	1
	0	0	0
	0	0	2
	0	0	0
	0	1	0
	2	0	0
	1	2	0
	0	0	1
CHI SQUARED	13.00	13.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG..
A BASIS	51.56	59.67	9.55
B BASIS	53.53	62.23	

TABLE C-18. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
31.06	39.89	6.00
31.33	39.89	5.00
31.86	42.03	5.00
31.86	42.03	7.00
32.40	41.77	7.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	31.70	41.12	00.77*
STD. DEV.	00.521	1.13	00.073*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG..
	0	0	0
	1	2	2
	1	0	0
	0	0	0
	0	0	0
	0	0	1
	2	0	0
	0	3	0
	0	0	2
	1	0	0
CHI SQUARED	9.00	21.00	13.00
NORMAL	YES	NO	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG..
A BASIS	28.71	34.6[a]	2.26
B BASIS	29.93	37.2[a]	

(a) Calculated assuming normality.

TABLE C-19. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 1300 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
31.47	34.40	3.00
30.49	32.53	3.00
33.67	35.47	4.00
31.47	33.87	4.00
31.73	35.20	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	31.63	34.29	00.53*
STD. DEV.	00.955	1.173	00.068*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	1	1	0
	0	0	0
	0	0	3
	0	1	0
	2	0	0
	1	1	0
	0	0	0
	0	1	0
	0	1	2
	1	0	0
CHI SQUARED	9.00	5.00	21.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

A BASIS	26.15	27.56	0.1(a)
B BASIS	28.37	30.30	

(a) Calculated assuming normality.

TABLE C-20. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 1600 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
31.59	33.20	1.00
30.25	31.06	2.00
29.99	30.25	1.50
30.25	31.06	1.00
29.99	30.52	1.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	30.41	31.22	00.10*
STD. DEV.	00.670	1.162	00.138*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	0	0	0
	0	0	0
	2	2	3
	0	0	0
	2	2	0
	0	0	0
	0	0	0
	0	0	1
	0	0	0
	1	1	1
CHI SQUARED	13.00	13.00	17.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

A BASIS	26.57	24.55	0.2(a)
B BASIS	28.13	27.26	

(a) Calculated assuming normality.

TABLE C-21. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.80	30.93	4.00
28.27	31.47	4.00
29.60	30.40	3.00
28.80	30.93	2.50
29.07	31.47	2.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	28.91	31.04	00.50*
STD. DEV.	00.484	00.448	00.103*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG.
1	1	0
0	0	2
0	0	0
0	0	0
2	2	1
0	0	0
1	0	0
0	0	0
0	2	2
1	0	0

	TYS	TUS	ELONG.
CHI SQUARED	9.00	13.00	13.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	26.13	28.47	00.81
B BASIS	27.26	29.51	

TABLE C-22. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
29.87	31.47	5.00
[illegible].00	30.67	2.00
28.8[illegible]	32.00	4.00
29.37	31.20	4.00
30.13	32.53	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	4	5	5
AVERAGE	29.47	31.57	00.54*
STD. DEV.	00.634	00.718	00.153*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG.
0	0	1
1	1	0
1	0	0
0	1	1
0	1	0
0	0	0
0	0	2
1	1	0
1	0	1
0	1	0

	TYS	TUS	ELONG.
CHI SQUARED	6.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	25.0(a)	27.45	00.45
B BASIS	26.8(a)	29.13	

(a) Calculated assuming normality.

TABLE C-23. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
25.74	27.84	2.50
27.31	29.99	3.50
26.77	28.92	4.00
27.58	29.72	3.00
26.24	28.65	4.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	26.72	29.02	00.52*
STD. DEV.	00.766	00.862	00.088*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	1	1	1
	0	0	0
	1	0	1
	0	1	0
	0	1	0
	1	0	1
	0	0	0
	1	1	0
	1	1	2
	0	0	0
CHI SQUARED	5.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	22.31	24.08	1.05
B BASIS	24.10	26.09	

TABLE C-24. STRENGTH DATA FOR R512E/Cb752, 5 T/P CYCLED, AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
25.44	26.77	2.00
26.24	27.31	3.00
25.97	27.31	3.50
24.90	26.77	3.00
27.04	28.11	4.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	25.92	27.25	00.48*
STD. DEV.	00.811	00.549	00.113*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	0	0	1
	1	2	0
	1	0	0
	0	0	0
	0	0	2
	1	2	0
	1	0	0
	0	0	1
	0	0	1
	1	1	0
CHI SQUARED	5.00	13.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	21.26	24.10	00.68
B BASIS	23.16	25.38	

TABLE C-25. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
56.53	65.87	16.00
55.47	65.33	16.00
56.53	66.40	17.50
56.27	66.13	16.00
56.80	65.87	16.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	56.32	65.92	1.21*
STD. DEV.	00.511	00.396	00.017*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	0
	0	0	0
	0	0	0
	0	0	4
	1	2	0
	0	0	0
	2	0	0
	0	1	0
	1	1	0
	0	0	1
CHI SQUARED	9.00	9.00	29.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	53.39	63.65	12.9 (a)
B BASIS	54.58	64.57	

(a) Calculated assuming normality.

TABLE C-26. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
31.33	40.70	5.00
32.13	41.50	5.00
30.79	31.06	2.00
31.59	39.63	5.00
31.33	40.43	5.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	31.43	38.66	00.62*
STD. DEV.	00.486	4.303	00.178*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	1
	0	0	0
	0	0	0
	0	0	0
	2	0	0
	0	1	0
	1	2	4
	0	1	0
	0	0	0
	1	0	0
CHI SQUARED	9.00	9.00	29.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	28.9	35.1	0.4 (a)
B BASIS	30.0	37.3	

(a) Calculated assuming normality.

TABLE C-27. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT 1300 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
29.60	31.20	3.00
30.40	32.53	2.00
32.30	34.13	3.00
31.47	33.87	4.00
30.93	32.53	3.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	30.98	32.85	0.47*
STD. DEV.	0.932	1.184	0.107*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	1	1	1
	0	0	0
	0	0	0
	1	2	0
	0	0	0
	1	0	3
	0	0	0
	1	0	0
	1	2	1
	0	0	0
CHI SQUARED	5.00	13.00	17.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	25.53	26.06	0.7[(a)]
B BASIS	27.79	28.82	

(a) Calculated assuming normality.

TABLE C-28. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT 1600 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
28.55	29.45	2.00
29.49	31.25	2.00
31.50	32.40	1.00
31.33	31.59	1.50
31.06	31.33	1.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	30.52	31.20	0.16*
STD. DEV.	1.211	1.163	0.151*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG.
	1	1	0
	0	0	2
	0	1	0
	1	0	0
	0	0	0
	0	1	1
	1	2	0
	1	0	0
	1	1	2
	0	0	0
CHI SQUARED	5.00	9.00	13.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	23.57	24.34	0.19
B BASIS	26.40	27.05	

TABLE C-29. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
29.33	30.40	3.00
28.53	29.60	2.00
30.13	30.93	1.50
30.40	31.20	3.00
30.40	31.20	2.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	29.76	30.67	00.35*
STD. DEV.	00.915	00.680	00.130*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG
1	1	1
0	0	0
1	0	0
0	1	2
0	0	0
0	0	0
1	1	0
2	2	0
0	0	2
0	0	0

	TYS	TUS	ELONG
CHI SQUARED	9.00	9.00	13.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	25.08	26.76	00.40
B BASIS	26.98	28.35	

TABLE C-30. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
30.13	30.67	2.00
29.60	31.47	3.50
29.87	30.93	2.00
29.07	30.40	2.50
29.87	30.40	2.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	29.71	30.77	00.37*
STD. DEV.	00.403	00.447	00.106*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG
1	0	0
0	0	0
0	2	3
1	0	0
0	1	0
0	0	0
2	1	1
0	0	0
1	0	0
0	1	1

	TYS	TUS	ELONG
CHI SQUARED	9.00	9.00	17.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	27.46	28.21	0.6(a)
B BASIS	28.34	29.25	

(a) Calculated assuming normality.

TABLE C-31. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
27.31	29.72	4.00
27.58	29.99	3.50
27.31	29.18	4.50
27.58	29.45	3.50
28.38	29.99	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	27.63	29.67	00.56*
STD. DEV.	00.434	00.352	00.067*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	1	1
	0	0	0
	2	1	0
	0	0	2
	2	0	0
	0	1	0
	0	0	0
	0	0	1
	0	2	0
	1	0	1
CHI SQUARED	13.00	9.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	25.11	27.64	1.52
B BASIS	26.13	28.47	

TABLE C-32. STRENGTH DATA FOR R512E/Cb752, 10 T/P CYCLED AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
23.96	26.24	3.50
24.63	26.51	3.00
24.36	26.77	2.00
24.36	27.04	3.00
24.36	26.77	4.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	24.25	26.67	00.48*
STD. DEV.	00.405	00.303	00.113*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	1
	0	0	0
	0	0	0
	0	1	0
	0	0	2
	0	0	0
	3	2	0
	0	0	1
	1	1	1
	0	0	0
CHI SQUARED	17.00	9.00	9.00
NORMAL	NO	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	21.9[(a)]	24.93	00.68
B BASIS	22.8[(a)]	25.63	

(a) Calculated assuming normality.

TABLE C-33. STRENGTH DATA FOR R512E/Cb752, 30 T/P CYCLED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
53.60	62.93	10.00
53.87	63.20	12.00
52.00	61.87	10.00
52.80	62.67	12.00
55.20	57.60	3.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	5	5	5
AVERAGE	53.49	61.65	00.93*
STD. DEV.	1.262	2.32	00.255*

(* = LOG BASE 10)

TALLY BY DECILES UNUER THE NORMAL CURVE

	TYS.	TUS.	ELONG..
	0	1	1
	1	0	0
	1	0	0
	0	0	0
	0	0	0
	1	1	0
	1	1	2
	0	2	2
	0	0	0
	1	0	0
CHI SQUARED	5.00	9.00	13.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG..
A BASIS	46.59	48.33	00.29
B BASIS	49.40	53.75	

TABLE C-34. STRENGTH DATA FOR R512E/Cb752, 30 T/P CYCLED, AT 2000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
29.18	31.33	2.00
28.65	29.45	0.00
28.27	28.80	2.50
0.00	29.60	1.50

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	3	4	3
AVERAGE	28.70	29.79	00.29*
STD. DEV.	00.457	1.081	00.111*

(* = LOG BASE 10)

TALLY BY DECILES UNUER THE NORMAL CURVE

	TYS.	TUS.	ELONG..
	0	0	0
	1	1	1
	0	0	0
	0	1	0
	1	1	0
	0	0	1
	0	0	0
	0	0	0
	1	0	1
	0	1	0
CHI SQUARED	7.00	6.00	7.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG..
A BASIS	23.8[(a)]	22.2[(a)]	0.1[(a)]
B BASIS	25.8[(a)]	25.3[(a)]	

(a) Calculated assuming normality.

TABLE C-35. STRENGTH DATA FOR R512E/Cb752, 30 T/P CYCLED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
29.72	32.93	2.00
30.52	32.66	2.00
26.51	28.11	0.00
28.65	30.25	4.00
27.05	28.92	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	4
AVERAGE	28.49	30.57	00.380*
STD. DEV.	1.7[illegible]	2.169	00.151*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	0	0
	2	1	0
	0	1	0
	0	0	3
	0	1	0
	1	0	0
	0	0	0
	1	0	0
	1	2	0
	0	0	1
CHI SQUARED	9.00	9.00	21.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	18.68	18.12	0.2(a)
B BASIS	22.67	23.19	

(a) Calculated assuming normality.

TABLE C-36. STRENGTH DATA FOR R512E/Cb752, 30 T/P CYCLED, AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
26.24	28.38	2.50
25.24	27.59	4.00
23.93	24.90	2.50
27.94	27.84	4.00
27.94	27.58	4.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	26.[illegible]	27.25	00.520*
STD. DEV.	1.319	1.357	00.114*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	0
	0	0	2
	0	0	0
	0	0	0
	0	0	0
	2	2	0
	0	1	0
	2	1	3
	0	0	0
	0	0	0
CHI SQUARED	13.00	9.00	21.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	18.51	19.47	0.7(a)
B BASIS	21.58	22.63	

(a) Calculated assuming normality.

TABLE C-37. STRENGTH DATA FOR VH109/C129Y, AS COATED, AT ROOM TEMPERATURE
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
59.44	73.09	19.00
60.51	74.70	16.00
61.58	76.31	19.00
62.12	75.50	17.50
59.47	72.82	19.00
61.04	75.77	19.00
65.06	81.12	17.00
62.38	77.64	18.00
62.92	77.11	18.00
62.12	76.84	16.00
63.47	77.87	15.00
65.33	75.47	16.00
64.53	78.13	19.00
64.53	78.13	18.00
64.53	78.13	17.00
65.60	79.20	17.00
64.27	77.87	16.00
63.47	76.80	18.00
64.53	78.13	17.00
65.87	80.53	17.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	20
AVERAGE	63.15	77.26	1.24*
STD. DEV.	1.939	2.154	0.031*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	3	2	1
	1	1	4
	3	2	0
	1	1	5
	1	3	0
	2	1	1
	0	6	4
	5	0	0
	3	2	5
	1	2	0
CHI SQUARED	10.00	12.00	22.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	56.78	70.15	13.7[a]
B BASIS	59.43	73.10	

(a) Calculated assuming normality.

TABLE C-38. STRENGTH DATA FOR VH109/C129Y, AS COATED, AT 1000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
0.00	0.00	8.00
0.00	0.00	5.00
0.00	0.00	5.00
36.35	53.55	7.00
37.48	56.22	8.00
36.68	53.55	8.00
39.09	53.55	10.00
35.68	53.01	10.00
36.68	53.55	8.00
35.88	52.48	8.00
38.93	54.93	10.00
38.40	56.00	9.00
37.97	53.87	7.00
0.00	0.00	9.00
0.00	0.00	9.00
33.33	47.47	9.00
34.40	0.00	9.00
0.00	0.00	8.00
43.20	53.33	11.00
38.13	54.93	7.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	14	13	20
AVERAGE	37.41	52.57	0.91*
STD. DEV.	2.324	2.154	0.090*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	2	1	2
	0	0	0
	1	0	3
	3	2	0
	1	5	6
	2	1	0
	2	0	5
	2	2	0
	0	2	3
	1	0	1
CHI SQUARED	6.00	17.00	22.00
NORMAL	YES	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	33.4	49.3	4.1[a]
B BASIS	35.0	51.3	

(a) Calculated assuming normality.

TABLE C-39. STRENGTH DATA FOR VH109/C129Y, AS COATED AT 1300 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
37.22	41.50	5.00
34.27	37.22	4.00
34.81	38.29	4.00
36.68	42.03	2.00
35.61	40.43	4.00
35.07	39.09	5.00
35.34	39.63	5.00
35.98	39.09	6.00
35.34	39.63	6.00
33.47	38.29	0.00
36.00	41.87	6.00
36.90	41.33	5.00
36.00	41.60	7.00
35.47	40.53	8.00
37.07	43.47	0.00
34.93	41.07	5.00
34.40	40.00	4.00
36.27	41.60	3.00
36.00	42.67	6.00
36.00	41.87	0.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	17
AVERAGE	35.59	40.56	00.68*
STD. DEV.	00.933	1.626	00.143*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	2	3	2
	1	2	0
	3	2	4
	2	1	0
	1	2	0
	1	0	5
	6	2	0
	1	5	4
	1	1	1
	2	2	1
CHI SQUARED	11.00	8.00	20.06
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	32.52	35.20	1.6 (a)
B BASIS	33.90	37.43	

(a) Calculated assuming normality.

TABLE C-40. STRENGTH DATA FOR VH109/C129Y, AS COATED AT 1600 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
37.22	39.89	3.00
35.07	36.41	2.00
33.73	35.61	3.00
35.07	35.61	2.00
36.41	38.82	4.00
32.66	33.20	1.00
34.27	35.61	3.00
33.20	35.34	3.00
35.07	36.14	2.00
34.27	35.34	3.00
36.96	38.67	3.00
35.73	37.60	3.00
36.53	38.40	4.00
36.53	38.40	2.00
35.80	37.07	3.00
36.00	37.60	2.00
37.37	38.40	3.00
35.73	37.33	2.50
36.90	38.67	2.00
36.86	38.40	3.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	20
AVERAGE	35.59	37.13	00.41*
STD. DEV.	1.365	1.661	00.140*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	3	1	1
	2	5	0
	0	1	6
	3	1	0
	0	1	1
	2	1	0
	1	2	9
	3	4	0
	6	3	1
	0	1	2
CHI SQUARED	16.00	10.00	42.00
NORMAL	NO	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	31.1 (a)	31.65	1.0 (a)
B BASIS	32.9 (a)	33.93	

(a) Calculated assuming normality.

TABLE C-41. STRENGTH DATA FOR VH109/C129Y, AS COATED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
33.73	36.68	2.50
32.93	35.61	2.00
34.00	36.14	2.00
34.54	35.88	1.00
34.81	36.95	2.00
34.27	36.95	2.00
33.73	35.61	2.00
35.07	36.14	1.00
34.54	36.68	3.00
35.17	36.41	2.00
36.00	39.20	2.00
35.73	38.40	1.00
36.00	37.07	1.00
35.20	37.07	1.50
36.00	37.60	1.50
36.27	38.13	2.00
36.80	39.47	1.00
36.80	38.67	1.00
37.07	38.13	00.50
37.33	40.53	1.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	20	20	20
AVERAGE	35.29	37.37	00.17*
STD. DEV.	1.230	1.368	00.193*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG.
1	2	1
3	3	7
3	1	0
1	4	0
3	2	0
0	1	2
1	0	0
4	3	8
2	1	1
2	3	1

	TYS	TUS	ELONG.
CHI SQUARED	7.00	7.00	40.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	31.21	32.86	0.4[(a)]
B BASIS	32.91	34.73	

(a) Calculated assuming normality.

TABLE C-42. STRENGTH DATA FOR VH109/C129Y, AS COATED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
34.27	37.75	2.00
33.47	38.29	2.00
34.81	38.02	1.00
34.81	38.82	1.00
36.95	42.39	1.00
32.66	36.14	2.00
33.20	36.95	2.00
32.93	36.68	2.00
34.00	36.95	3.00
36.27	41.60	3.00
35.20	39.20	1.00
36.80	41.07	2.00
34.67	38.67	1.00
35.73	39.47	1.00
35.20	38.93	1.00
35.47	39.20	1.00
35.20	39.47	2.00
35.73	39.73	2.00
37.07	40.80	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	19	19	19
AVERAGE	34.97	38.95	00.19*
STD. DEV.	1.326	1.689	00.177*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG.
3	2	0
1	2	8
2	2	0
0	1	0
3	3	0
3	2	0
1	3	0
2	0	9
1	2	0
3	2	2

	TYS	TUS	ELONG.
CHI SQUARED	5.74	3.63	59.42
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	30.32	33.01	0.4[(a)]
B BASIS	32.24	35.46	

(a) Calculated assuming normality.

TABLE C-43. STRENGTH DATA FOR VH109/C129Y, AS COATED AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

IYS. KSI	IUS. KSI	ELONG.. %
31.54	39.09	3.00
32.93	38.29	3.50
32.13	38.02	3.50
32.93	38.02	4.50
34.00	37.75	3.00
32.13	35.88	3.00
30.25	35.34	4.00
31.33	36.14	3.00
32.93	36.41	2.50
32.93	38.02	2.50
33.33	39.20	3.50
33.66	38.67	3.00
34.13	39.73	3.00
34.13	39.47	3.00
33.87	39.47	3.50
32.53	38.13	4.00
32.53	37.60	3.00
33.60	37.33	4.00
32.80	37.87	3.00
32.80	37.60	4.00

Design Allowables Computation

	IYS. KSI	IUS. KSI	ELONG.. %
NO. OF DATA	20	20	20
AVERAGE	32.82	37.90	00.52*
STD. DEV.	00.996	1.229	00.070*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	IYS.	IUS.	ELONG.
	2	3	2
	1	1	0
	2	0	9
	2	1	0
	2	4	0
	4	4	0
	1	1	4
	2	1	0
	2	4	4
	2	1	1
CHI SQUARED	3.00	11.00	39.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	IYS.	IUS.	ELONG.
A BASIS	29.54	33.85	2.0[(a)]
B BASIS	30.90	35.53	

(a) Calculated assuming normality.

TABLE C-44. STRENGTH DATA FOR VH109/C129Y, AS COATED AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

IYS. KSI	IUS. KSI	ELONG.. %
29.45	32.40	2.50
29.18	32.66	2.50
29.18	32.93	2.50
28.92	32.13	1.50
28.92	31.33	3.00
27.84	29.99	1.50
27.31	29.99	2.00
28.11	30.52	2.50
28.11	30.25	2.00
27.58	29.72	2.00
26.65	31.59	1.50
29.33	31.47	2.50
29.60	33.87	2.50
28.80	32.00	3.00
28.80	31.47	1.50
29.33	33.07	3.00
29.60	31.73	1.50
28.27	31.47	4.00
29.07	32.80	2.00
30.13	33.60	3.00

Design Allowables Computation

	IYS. KSI	IUS. KSI	ELONG.. %
NO. OF DATA	20	20	20
AVERAGE	28.81	31.75	00.35*
STD. DEV.	00.737	1.217	00.126*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	IYS.	IUS.	ELONG.
	3	3	5
	2	2	6
	1	0	0
	0	1	4
	3	5	0
	2	1	0
	3	1	6
	2	2	0
	3	3	4
	1	2	1
CHI SQUARED	5.00	9.00	27.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	IYS.	IUS.	ELONG.
A BASIS	26.38	27.74	0.9[(a)]
B BASIS	27.39	29.41	

(a) Calculated assuming normality.

TABLE C-45. STRENGTH DATA FOR VH109/C129Y, WELDED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
68.55	83.53	19.00
61.35	74.31	16.00
58.76	66.82	5.00
59.62	72.00	10.00
62.77	72.00	7.50
59.62	72.00	10.00
59.62	71.43	8.00
59.91	71.72	9.00
63.36	74.60	7.50
63.36	74.31	7.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	61.49	73.27	0.950*
STD. DEV.	2.94	4.235	0.148*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG
	0	1	1
	1	0	0
	4	0	0
	0	3	4
	2	1	0
	0	2	1
	0	1	3
	2	0	0
	0	0	0
	1	1	1
CHI SQUARED	16.00	22.00	18.00
NORMAL	NO	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	51.1	62.3[a]	3.2[a]
B BASIS	55.0	66.3[a]	

(a) Calculated assuming normality.

TABLE C-46. STRENGTH DATA FOR VH109/C129Y, WELDED, AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
36.58	49.54	6.00
36.58	43.83	8.00
39.46	53.28	6.00
35.71	53.28	8.00
36.05	52.12	0.00
36.87	53.57	6.00
36.29	53.30	8.00
36.58	49.54	8.00
35.43	51.27	8.00
35.43	53.28	8.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	9
AVERAGE	36.49	51.67	0.868*
STD. DEV.	1.161	1.764	0.062*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG
	0	0	3
	2	4	0
	1	0	0
	1	0	0
	1	1	0
	3	0	0
	1	0	0
	0	1	6
	0	4	0
	1	0	0
CHI SQUARED	8.00	24.00	41.00
NORMAL	YES	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	31.87	44.6[a]	4.0[a]
B BASIS	33.76	47.5[a]	

(a) Calculated assuming normality.

TABLE C-47. STRENGTH DATA FOR VH109/C129Y, WELDED, AT 1300 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
36.00	44.07	5.00
36.00	42.34	4.00
36.87	42.91	4.00
36.54	45.22	5.00
26.79	36.00	5.00
36.58	44.35	2.00
37.73	46.66	4.50
37.73	45.22	2.50
35.71	42.63	2.50
35.43	43.49	3.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	10	10	10
AVERAGE	35.54	43.29	00.55*
STD. DEV.	3.172	2.891	00.148*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG..
	1	1	1
	0	0	2
	0	0	0
	0	1	1
	1	2	0
	3	1	0
	3	2	2
	2	2	1
	0	1	3
	0	0	0
CHI SQUARED	14.00	6.00	10.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG..
A BASIS	22.91	31.78	00.92
B BASIS	28.07	36.48	

TABLE C-48. STRENGTH DATA FOR VH109/C129Y, WELDED, AT 1600 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS. KSI	TUS. KSI	ELONG.. %
37.44	39.17	2.50
36.87	38.59	2.00
36.58	37.44	3.00
36.29	36.58	2.50
36.00	36.87	2.50
29.99	31.11	2.00
35.43	36.87	2.00
35.58	38.88	2.00
35.14	36.87	3.00
35.71	36.87	2.00

Design Allowables Computation

	TYS. KSI	TUS. KSI	ELONG.. %
NO. OF DATA	10	10	10
AVERAGE	35.51	36.92	00.37*
STD. DEV.	2.36	2.257	00.074*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS.	TUS.	ELONG..
	1	1	0
	0	0	5
	0	0	0
	1	0	0
	2	5	0
	2	1	0
	3	0	3
	2	1	0
	0	2	0
	0	0	2
CHI SQUARED	12.00	22.00	28.00
NORMAL	YES	NO	NO

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG..
A BASIS	26.12	27.9[a]	1.7[a]
B BASIS	29.96	31.6[a]	

(a) Calculated assuming normality.

TABLE C-49. STRENGTH DATA FOR VH109/C129Y, WELDED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS., KSI	TUS., KSI	ELONG., %
36.00	36.87	1.00
35.29	38.02	2.00
34.85	35.43	1.00
35.71	36.30	1.00
35.71	37.44	2.00
34.85	35.71	2.00
35.14	35.71	2.00
33.70	36.00	1.50
36.58	36.87	2.00
36.58	34.02	2.00

Design Allowables Computation

	TYS., KSI	TUS., KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	35.54	36.61	00.20*
STD. DEV.	00.912	00.975	00.142*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS.	TUS.	ELONG.
1	0	3
0	3	0
2	2	0
1	0	0
0	0	1
2	0	0
1	2	0
1	0	6
2	1	0
0	2	0

	TYS.	TUS.	ELONG.
CHI SQUARED	6.00	12.00	36.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	31.91	32.73	0.4[(a)]
B BASIS	33.39	34.31	

(a) Calculated assuming normality.

TABLE C-50. STRENGTH DATA FOR VH109/C129Y, WELDED AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS., KSI	TUS., KSI	ELONG., %
36.00	37.15	3.00
34.85	37.44	3.00
36.03	38.31	3.00
33.70	35.71	2.00
33.94	36.29	1.00
35.71	39.17	3.00
35.43	37.44	1.00
35.71	37.44	1.00
35.43	36.87	3.00

Design Allowables Computation

	TYS., KSI	TUS., KSI	ELONG., %
NO. OF DATA	9	9	9
AVERAGE	35.2[illegible]	37.31	00.30*
STD. DEV.	01.047	1.22[illegible]	00.231*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS.	TUS.	ELONG.
2	1	3
0	1	0
0	0	0
1	1	0
0	1	0
0	3	1
2	0	0
2	0	5
2	1	0
0	1	0

	TYS.	TUS.	ELONG.
CHI SQUARED	9.89	7.67	29.89
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	30.34	31.46	0.2[(a)]
B BASIS	32.32	33.84	

(a) Calculated assuming normality.

TABLE C-51. STRENGTH DATA FOR VH109/C129Y, WELDED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
33.99	37.15	2.50
33.41	37.44	2.00
33.41	36.00	3.00
36.00	40.61	3.00
33.99	35.43	2.50
32.83	35.14	3.00
33.99	36.00	2.50
31.39	33.99	2.50
33.99	36.87	3.50
35.14	37.44	2.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	33.81	36.61	00.43*
STD. DEV.	1.241	1.792	00.068*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG.
1	1	1
0	0	0
1	2	0
2	2	5
0	0	0
4	1	0
0	3	0
0	0	3
1	0	0
1	1	1

	TYS	TUS	ELONG.
CHI SQUARED	14.00	10.00	26.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	28.88	29.47	0.1(a)
B BASIS	30.89	32.39	

(a) Calculated assuming normality.

TABLE C-52. STRENGTH DATA FOR VH109/C129Y, WELDED AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.51	30.53	5.00
27.07	28.51	3.00
29.09	30.82	3.00
28.23	29.95	1.50
27.36	29.67	2.50
26.21	27.94	3.00
28.23	29.67	2.00
28.80	31.39	3.00
28.51	31.11	3.00
28.23	29.95	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	10	10	10
AVERAGE	28.02	29.95	00.43*
STD. DEV.	00.861	1.095	00.142*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

TYS	TUS	ELONG.
1	2	1
1	0	2
1	0	0
0	2	0
0	2	1
3	0	0
0	0	5
2	2	0
2	1	0
0	1	1

	TYS	TUS	ELONG.
CHI SQUARED	10.00	8.00	22.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	24.52	25.60	0.7(a)
B BASIS	25.95	27.38	

(a) Calculated assuming normality.

TABLE C-53. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
61.58	74.70	19.00
61.04	74.16	17.00
61.31	74.70	15.00
59.71	72.56	18.00
59.17	71.75	17.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	60.56	73.57	1.23*
STD. DEV.	1.059	1.345	00.038*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	1
	0	0	0
	1	1	0
	0	0	0
	0	0	2
	0	0	0
	1	1	0
	1	2	1
	1	0	1
	0	0	0
CHI SQUARED	5.00	9.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	54.48	65.85	10.35
B BASIS	56.95	68.99	

TABLE C-54. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
39.63	55.15	8.00
37.75	51.14	8.00
38.02	53.55	9.00
38.02	52.48	6.00
37.75	51.94	8.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	38.23	52.85	00.89*
STD. DEV.	00.792	1.555	00.065*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	0	1
	0	1	0
	2	1	0
	2	0	0
	0	1	0
	0	0	3
	0	1	0
	0	0	0
	0	0	1
	1	1	0
CHI SQUARED	13.00	5.00	17.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	33.69	43.93	9.3[a]
B BASIS	35.54	47.55	

(a) Calculated assuming normality.

TABLE C-55. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT 1300 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
37.75	43.91	4.00
35.34	40.70	3.00
35.07	40.96	3.00
34.81	39.63	3.00
35.34	39.89	2.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	35.66	41.02	0.49*
STD. DEV.	1.188	1.708	0.073*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	0	0
	0	0	1
	1	2	0
	3	0	0
	0	2	3
	0	0	0
	0	0	0
	0	0	0
	0	0	0
	1	1	1
CHI SQUARED	17.00	13.00	17.00
NORMAL	NO	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	28.8[a]	31.21	1.2[a]
B BASIS	31.6[a]	35.20	

(a) Calculated assuming normality.

TABLE C-56. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT 1600 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
35.34	37.75	1.00
36.41	38.29	2.00
36.14	39.36	2.00
33.73	35.88	2.00
35.07	36.95	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	35.34	37.65	0.24*
STD. DEV.	1.055	1.32	0.135*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	1
	0	0	0
	0	1	0
	1	0	0
	0	0	0
	1	1	0
	0	1	4
	1	0	0
	1	0	0
	0	1	0
CHI SQUARED	5.00	5.00	29.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	29.28	30.07	0.3[a]
B BASIS	31.74	33.15	

(a) Calculated assuming normality.

TABLE C-57. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
35.61	38.29	1.00
35.34	38.29	1.00
35.07	37.48	1.00
35.07	36.68	1.00
33.73	36.95	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	34.96	37.54	00.06*
STD. DEV.	00.725	00.744	00.135*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	0	0
	0	1	0
	0	1	0
	0	0	4
	0	1	0
	2	0	0
	1	0	0
	0	0	0
	1	2	0
	0	0	1
CHI SQUARED	9.00	9.00	29.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	30.80	33.26	0.2(a)
B BASIS	32.49	35.00	

(a) Calculated assuming normality.

TABLE C-58. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
35.34	38.29	3.00
36.95	40.96	4.00
33.73	37.75	3.00
35.34	37.75	4.00
35.07	37.75	2.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	35.29	38.50	00.51*
STD. DEV.	1.145	1.395	00.089*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	0	0
	0	0	1
	0	3	0
	0	0	2
	1	1	0
	2	0	0
	0	0	0
	0	0	0
	0	0	2
	1	1	0
CHI SQUARED	9.00	17.00	13.00
NORMAL	YES	NO	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	28.71	30.5(a)	1.00
B BASIS	31.39	33.7(a)	

(a) Calculated assuming normality.

TABLE C-59. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
31.59	34.81	4.00
31.86	35.61	3.00
31.33	34.27	3.50
31.06	34.81	2.50
31.06	33.20	3.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	31.38	34.54	00.51*
STD. DEV.	00.347	00.889	00.078*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG
	0	1	1
	2	0	0
	0	0	0
	0	1	1
	1	0	0
	0	0	0
	0	2	2
	1	0	0
	0	1	1
	1	0	0
CHI SQUARED	9.00	9.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	29.39	29.44	1.16
B BASIS	30.20	31.51	

TABLE C-60. STRENGTH DATA FOR VH109/C129Y, 5 T/P CYCLED AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
27.31	28.38	4.00
27.04	29.45	3.00
25.97	28.11	3.50
27.04	29.72	3.00
28.65	31.06	2.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	27.20	29.34	00.48*
STD. DEV.	00.959	1.178	00.113*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG
	1	0	1
	0	1	0
	0	1	0
	0	0	0
	2	0	2
	1	1	0
	0	1	0
	0	0	1
	0	0	1
	1	1	0
CHI SQUARED	9.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	21.70	22.58	00.68
B BASIS	23.93	25.33	

TABLE C-61. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
59.71	71.75	16.00
58.90	70.41	17.00
61.31	74.97	17.00
61.04	74.97	16.00
65.06	78.45	16.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	61.20	74.11	1.21*
STD. DEV.	2.369	3.145	00.014*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	0	0
	1	1	0
	1	1	3
	0	0	0
	1	0	0
	1	0	0
	0	2	0
	0	0	0
	0	0	2
	1	1	0
CHI SQUARED	5.00	9.00	21.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	47.60	56.05	12.5 (a)
B BASIS	53.13	63.39	

(a) Calculated assuming normality.

TABLE C-62. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
38.29	52.48	7.00
39.63	55.96	6.00
37.48	52.48	6.00
35.34	49.53	7.00
36.68	49.80	6.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	37.48	52.05	00.80*
STD. DEV.	1.620	2.601	00.037*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	0	0
	0	2	0
	0	0	3
	1	0	0
	1	0	0
	0	2	0
	1	0	0
	0	0	0
	0	0	2
	1	1	0
CHI SQUARED	5.00	13.00	21.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	28.18	37.11	3.9 (a)
B BASIS	31.96	43.19	

(a) Calculated assuming normality.

TABLE C-63. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 1300 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
36.68	39.63	1.00
39.63	46.32	5.00
37.48	43.64	4.00
37.22	42.57	3.00
36.68	39.09	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	37.54	42.25	00.45*
STD. DEV.	1.220	2.977	00.269*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	0	1
	0	2	0
	2	0	0
	1	0	0
	1	0	0
	0	1	2
	0	1	0
	0	0	1
	0	0	1
	1	1	0
CHI SQUARED	9.00	9.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	30.53	25.16	00.08
B BASIS	33.38	32.11	

TABLE C-64. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 1600 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
35.34	35.61	0.00
37.48	39.36	1.00
36.41	38.29	2.00
34.54	35.88	2.00
33.25	35.07	1.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	4
AVERAGE	35.39	36.84	00.15*
STD. DEV.	1.653	1.872	00.174*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	0	0
	0	1	2
	0	1	0
	1	1	0
	1	0	0
	0	0	0
	0	0	0
	1	1	0
	1	0	2
	0	1	0
CHI SQUARED	5.00	5.00	16.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	25.90	26.09	0.1[(a)]
B BASIS	29.76	30.46	

(a) Calculated assuming normality.

TABLE C-65. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
33.47	36.41	1.00
33.73	34.54	2.00
33.47	35.88	1.00
34.81	37.22	1.00
32.66	33.73	1.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	33.63	35.56	00.06*
STD. DEV.	00.774	1.412	00.135*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	1	0
	1	0	0
	0	1	0
	0	0	4
	2	0	0
	1	1	0
	0	0	0
	0	1	0
	0	1	0
	1	0	1
CHI SQUARED	9.00	5.00	29.00
NORMAL	YES	YES	NO

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	29.19	27.45	0.2[(a)]
B BASIS	30.99	30.75	

(a) Calculated assuming normality.

TABLE C-66. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
34.27	36.95	3.50
34.27	36.68	3.00
35.07	36.95	2.50
34.54	36.41	2.00
32.93	34.27	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	34.22	36.25	00.44*
STD. DEV.	00.790	1.138	00.093*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	1
	0	0	0
	0	0	0
	0	0	1
	0	0	0
	2	1	0
	1	1	2
	0	2	0
	1	0	1
	0	0	0
CHI SQUARED	9.00	9.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	29.68	29.76	00.80
B BASIS	31.53	32.40	

TABLE C-67. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
26.77	32.66	4.00
31.86	35.37	3.00
31.59	35.34	2.00
31.33	34.00	2.50
31.59	33.47	2.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	30.63	34.11	00.44*
STD. DEV.	2.165	1.113	00.114*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

1	1	0
0	0	1
0	1	0
0	0	2
0	1	0
0	0	0
3	0	1
1	0	0
0	2	0
0	0	1

	TYS	TUS	ELONG.
CHI SQUARED	17.00	9.00	9.00
NORMAL	NO	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	18.2[(a)]	27.72	00.62
B BASIS	23.2[(a)]	30.31	

(a) Calculated assuming normality.

TABLE C-68. STRENGTH DATA FOR VH109/C129Y, 10 T/P CYCLED, AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
27.58	29.72	3.50
25.70	27.84	2.00
27.94	29.18	3.50
25.7[illegible]	28.11	3.00
27.58	28.38	2.50

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	26.72	28.65	00.45*
STD. DEV.	00.957	00.782	00.104*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

0	0	1
2	1	0
0	1	1
0	1	0
0	0	0
0	0	1
1	0	0
0	1	0
2	0	2
0	1	0

	TYS	TUS	ELONG.
CHI SQUARED	13.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	21.23	24.16	00.72
B BASIS	23.46	25.98	

TABLE C-69. STRENGTH DATA FOR VH109/C129Y, 30 T/P CYCLED, AT ROOM TEMPERATURE (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
61.04	74.57	17.00
59.37	71.49	15.00
61.04	75.50	14.00
50.60	70.15	13.00
52.48	63.45	14.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	56.71	71.43	1.16*
STD. DEV.	4.886	5.204	0.044*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG
	0	1	0
	2	0	1
	0	0	0
	0	0	2
	0	1	0
	0	1	0
	1	0	1
	0	1	0
	2	1	0
	0	0	1
CHI SQUARED	13.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	28.66	41.56	8.14
B BASIS	40.06	53.70	

TABLE C-70. STRENGTH DATA FOR VH109/C129Y, 30 T/P CYCLED, AT 1000 F (BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
39.63	55.42	2.00
37.75	51.14	5.00
38.02	53.55	4.00
38.02	52.48	3.00
38.02	51.94	3.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	38.29	52.91	0.51*
STD. DEV.	0.759	1.656	0.150*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG
	0	0	1
	0	1	0
	1	1	0
	3	1	0
	0	0	2
	0	0	0
	0	1	0
	0	0	1
	0	0	1
	1	1	0
CHI SQUARED	17.00	5.00	9.00
NORMAL	NO	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG
A BASIS	33.9[(a)]	43.40	0.45
B BASIS	35.7[(a)]	47.26	

(a) Calculated assuming normality.

TABLE C-71. STRENGTH DATA FOR VH109/C129Y, 30 T/P CYCLED, AT 1800 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS., KSI	TUS., KSI	ELONG., %
34.00	37.22	3.00
33.73	36.41	2.00
34.54	36.95	3.50
33.20	37.75	4.00
35.07	37.75	3.50

Design Allowables Computation

	TYS., KSI	TUS., KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	34.11	37.22	00.49*
STD. DEV.	00.723	00.568	00.116*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

0	1	1
1	0	0
0	0	0
1	1	0
1	0	1
0	1	0
0	0	2
1	0	0
0	2	1
1	0	0

	TYS.	TUS.	ELONG.
CHI SQUARED	5.00	9.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	29.96	33.95	00.67
B BASIS	31.64	35.28	

TABLE C-72. STRENGTH DATA FOR VH109/C129Y, 30 T/P CYCLED, AT 2000 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS., KSI	TUS., KSI	ELONG., %
30.52	33.47	2.50
31.59	35.88	3.50
34.00	38.02	2.50
31.59	36.68	3.00
31.06	34.27	2.00

Design Allowables Computation

	TYS., KSI	TUS., KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	31.75	35.66	00.42*
STD. DEV.	1.333	1.829	00.092*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

0	0	1
1	1	0
0	1	0
1	0	2
2	0	0
0	1	0
0	0	0
0	1	1
0	0	0
1	1	1

	TYS.	TUS.	ELONG.
CHI SQUARED	9.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS.	TUS.	ELONG.
A BASIS	24.10	25.16	00.79
B BASIS	27.21	29.43	

TABLE C-73. STRENGTH DATA FOR VH109/C129Y, 30 T/P CYCLED, AT 2200 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
28.92	31.59	2.50
27.04	31.59	2.50
28.11	31.59	3.00
27.84	30.79	4.50
26.51	30.52	4.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	27.68	31.22	00.51*
STD. DEV.	00.939	00.521	00.117*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	0	1	0
	1	0	2
	1	1	0
	0	0	0
	0	0	1
	1	0	0
	1	0	0
	0	3	1
	0	0	1
	1	0	0
CHI SQUARED	5.00	17.00	9.00
NORMAL	YES	NO	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	22.29	28.2 (a)	00.68
B BASIS	24.48	29.4 (a)	

(a) Calculated assuming normality.

TABLE C-74. STRENGTH DATA FOR VH109/C129Y, 30 T/P CYCLED, AT 2400 F
(BASED ON UNCOATED SPECIMEN DIMENSIONS)

Tensile Test Data

TYS, KSI	TUS, KSI	ELONG., %
29.99	30.79	2.00
29.72	31.33	2.00
31.06	31.86	1.50
27.58	28.65	3.00
28.92	30.25	4.00

Design Allowables Computation

	TYS, KSI	TUS, KSI	ELONG., %
NO. OF DATA	5	5	5
AVERAGE	29.45	30.58	00.37*
STD. DEV.	1.298	1.233	00.168*

(* = LOG BASE 10)

TALLY BY DECILES UNDER THE NORMAL CURVE

	TYS	TUS	ELONG.
	1	1	0
	0	0	1
	0	0	0
	1	1	2
	0	0	0
	1	1	0
	1	0	0
	0	1	1
	1	1	0
	0	0	1
CHI SQUARED	5.00	5.00	9.00
NORMAL	YES	YES	YES

MIL-HDBK-5 A + B VALUES

	TYS	TUS	ELONG.
A BASIS	22.00	23.50	00.26
B BASIS	25.03	26.38	