

**Atlas of Stress Relaxation Curves for
Beryllium Copper and Selected
Copper Alloy Spring Materials**

Atlas of Stress Relaxation Curves for Beryllium Copper and Selected Copper Alloy Spring Materials

by

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ABSTRACT

Stress relaxation data are presented for all commercial strip tempers of beryllium copper alloys C17200, C17510 and C17410. The data are the results of an extensive test program involving tapered cantilever beam specimens stressed in bending. Data are presented in isothermal graphical format. Temperatures of 100 C to 200 C (212 F to 392 F) and beyond are represented, as are actual exposure times to 10,000 hr. A summary graph of these beryllium copper data in Larson-Miller parameter format is included. The influence of increasing initial stress level from 50% of the 0.01% offset yield strength to 100% of the 0.2% offset yield strength is also shown. For comparison purposes, isothermal stress relaxation data through 1000 hr exposure at 150 C (300 F) and 200 C are also reported for selected copper alloy spring materials: C72900, C19400, C72500, C68800, C51000, C52100, C7025 and C26000.

INTRODUCTION

Beryllium copper strip materials are extensively employed in the manufacture of electrical and electronic connectors. In such applications, these materials are typically incorporated as high strength, current carrying springs utilizing bending stresses to maintain circuit integrity between mating parts. Current trends in automotive, computer and communications electronics present connector designers with challenges of smaller packages, increased component densities and higher operating temperatures. With reliability of connector performance dependent upon stability of contact pressure over time, the stress relaxation behavior of connector alloys is an important material selection criterion for these applications.

FACTORS INFLUENCING STRESS RELAXATION

Stress relaxation is defined as the decrease of stress or force at constant strain with time at a given temperature. Stress relaxation differs from creep, as shown in Figure 1. Creep is the increase in strain

with time at constant stress. Stress relaxation is manifested in connectors as loss of spring or normal force. This phenomenon is not confined to connector alloys, any material subjected to stress at elevated temperatures for long periods of time will exhibit stress relaxation. In addition to springs, components such as clamps, press fitted joints, gaskets, bolts, rivets and other types of fasteners will relax over time.

Stress relaxation is a thermally activated metallurgical process, influenced principally by exposure temperature, but also by time and initial applied stress level. At elevated temperature, elastic strain is gradually converted to plastic strain (permanent set). The rate of this strain conversion increases with increasing temperature. Crystal defects called dislocations migrate under the influence of the applied stress and temperature. As each dislocation moves, a plane of atoms in the crystal lattice is shifted in the direction of motion. The net result of many dislocations moving over a long time is a gradual increase in permanent set as increasing numbers of atomic planes are displaced in the same direction. The effect of higher initial stress levels is to increase the magnitude of stress relaxation at a given exposure temperature and time.

Stress relaxation behavior of materials is dependent upon composition and strengthening mechanism. Both of these factors influence dislocation migration. Copper alloys strengthened only by solid solution alloying elements and cold working, e.g., the brasses and bronzes, have high initial densities of dislocations and few microstructural obstacles to their migration under applied elastic stress and temperature. These alloys exhibit poor resistance to stress relaxation. Copper alloys strengthened by heat treatment contain numerous uniformly distributed submicroscopic barriers to dislocation migration in the form of hardening precipitates, as in the beryllium coppers, or periodic arrays of composition fluctuation, as in alloys strengthened by spinodal decomposition. These heat treated materials exhibit good resistance to stress relaxation.

Another factor is melting temperature. Alloys for which a given exposure temperature is a small fraction of the melting temperature typically exhibit greater resistance to stress relaxation than do alloys for which the exposure temperature is a larger fraction of the melting temperature.

From a knowledge of the stress relaxation behavior of current carrying spring alloys, connector designers can determine by how much the room temperature spring force must be increased to compensate for time-dependent stress loss. This will assure that a particular minimum spring force is retained throughout the life of the connector. A comprehensive collection of stress relaxation data for most commercially available strip tempers of beryllium copper alloys and selected

other copper alloys accompanies this discussion. A wide range of temperatures is covered, as is a range of initial stress levels.

STRESS RELAXATION TEST METHODS

There are two commonly used stress relaxation tests for flat spring materials stressed in bending, both described in ASTM E 328, "Standard Methods for Stress Relaxation Tests for Material and Structures". One method is a tapered cantilever beam test, the other a mandrel test, as shown in Figure 2 (a) and (b).

The mandrel test requires cylinders of specific diameter, sufficient to generate an outer fiber bending stress equal to the target initial stress level. The cantilevered beam test utilizes adjustable test fixtures to deflect specimens to target initial stress levels. The taper in the test specimen assures a constant radius of curvature, and thus a constant bending stress over the deflected beam length. Both types of stress relaxation tests yield comparable results over a wide range of temperatures and times, as noted in Figure 2 (c). All of the stress relaxation data in this discussion were generated from cantilever beam tests.

Test specimens were fixtured and the initial position of a reference point at the free end of the beam was recorded. Specimens were then deflected a predetermined amount to establish the desired initial outer fiber stress in the beam. Initial stress levels were expressed as a fraction of the material's yield strength, e.g., 75% of the 0.2% offset yield strength. The fixtured, deflected specimens were then exposed to selected temperatures for specified times. After exposure, the deflecting fixture was backed-off and the final position of the reference point at the beam end was measured. If permanent set occurred, stress relaxation was deemed to have taken place.

Relaxation was manifested in a STRESS LOSS, but the normal convention in the literature is to report stress relaxation resistance in terms of the REMAINING STRESS (percentage of the initial stress surviving after the indicated exposure). This was computed by the expression:

$$\% \text{ Remaining Stress} = \frac{\text{Initial Deflection} - \text{Final Deflection}}{\text{Initial Deflection}} \times 100\%$$

The total permanent set measured in this approach has two components--one thermal, permanent set from relaxation at elevated temperature; the other mechanical, plastic deformation from the initial beam deflection at room temperature. For the low initial stress levels reported in this discussion, the mechanical component of permanent set was quite small, typically 1% or less of the initial deflection, and can be ignored. Where initial stress levels are large, compen-

sation must be made for room temperature mechanical deformation when computing the remaining stress.

The range of exposure temperatures reflect the end use applications of the material. Electronic connectors typically experience ambient temperatures of 100 C to 125 C (212 F to 257 F). Applications in automotive and high density miniaturized electronic components extend this range to 150 C (300 F) and beyond. Material for burn-in connectors is tested at temperatures up to 200 C (392 F). Much of the stress relaxation literature restricts actual exposure times to 1000 hr or less, for practical reasons. Longer time relaxation data are frequently extrapolated from short time/high temperature data. This discussion presents stress relaxation behavior for actual exposure times as long as 10,000 hr.

STRESS RELAXATION DATA REPORTING TECHNIQUES

Stress relaxation data are typically reported in one of three manners: (1) isothermally, (2) isochronally or (3) as a function of the Larson-Miller parameter which combines both temperature and time. Examples of each type of presentation are shown in Figure 3 (a) to (c). This discussion uses the convention of isothermal plots to provide a simple tool for directly comparing the stress relaxation behavior of materials within a given operating temperature envelope.

Larson-Miller plots compress a considerable amount of information into a single graph, but are somewhat more difficult to read and interpret. For this reason, use of Larson-Miller plots in this discussion is confined to a single summary graph of beryllium copper alloy stress relaxation behavior. To read a Larson-Miller plot, select the time of interest on the right hand axis. Extend a horizontal line to the temperature line of interest. Extend a line vertically, upward or downward, to intersect the material curve of interest. Lastly, extend a line horizontally to the left hand axis to read the remaining stress level. The lower the position and the steeper the slope of a curve on a Larson-Miller plot, the less resistant that material is to stress relaxation.

MATERIALS TESTED

Beryllium copper materials tested included C17200 (Alloys 25, 190 and 290), C17510 (Alloy 3) and C17410 (Alloy 174). Alloys 25, 190 and 290 are classified as high strength materials. Alloys 3 and 174 are classified as high conductivity materials. Other selected copper alloys tested included C72900, C19400, C72500, C68800, C51000, C52100, C7025 and C26000. The nominal compositions of these alloys, the tempers tested and their respective yield strengths are summarized in Tables I and II. Test specimens were all longitudinally oriented (axis parallel

to the rolling direction). While many electronic connectors are stamped in a transverse orientation, some are oriented longitudinally. The beryllium copper alloys typically exhibit low directionality of mechanical properties. Experiments have shown that stress relaxation behavior is essentially non-directional in beryllium copper strip as well.

STRESS RELAXATION DATA

Isothermal Stress Relaxation Curves

Figures 4 to 12 present beryllium copper stress relaxation data in the isothermal mode. Initial stress levels of either 100% of the 0.01% offset yield strength or 75% of the 0.2% offset yield strength are featured. For the alloys tested in this discussion, these two relative values of initial stress were essentially comparable in actual applied stress level and may be used interchangeably.

The materials in these isothermal plots have been grouped by commercial designation, indicating the alloy and type of strengthening heat treatment applied. Figures 4 to 6 represent, respectfully, the 125 C to 316 C behavior of Alloy 25 in the AT to HT tempers. This is C17200 composition strip with 0% to 37% cold work, age hardened to peak strength at 316 C (600 F) for 2 to 3 hr.

Figures 7 to 9 represent the 100 C to 316 C behavior of Alloys 190 AM to XHMS, or C17200 strip mill hardened to a series of ascending strength tempers by a proprietary process. The thermal relaxation of C17200 is rapid and severe at 260 C and 316 C. The material is not commercially employed at these temperatures, and the data are included here mainly for academic interest. Figure 10 shows the 100 C to 200 C behavior of Alloys 290 TM02 to TM06. This is C17200 composition strip mill hardened by a special proprietary process to achieve improved combinations of strength and formability compared to Alloys 190 AM to XHMS.

Figure 11 shows the 100 C to 200 C behavior of Alloy 3 AT & HT, or mill hardened C17510 strip. Figure 12 shows the 100 C to 200 C behavior of Alloy 174 HT, or mill hardened C17410 strip.

Influence of Initial Stress Level

Isothermal stress relaxation plots showing the influence of initial stress level appear in Figures 13 and 14. The former depicts Alloy 190 XHM, the latter shows Alloy 174 HT. Increasing the initial stress from as low as 50% of the 0.01% offset yield strength to as high as 100% of the 0.2% yield strength contributes only slightly to increased stress relaxation in both materials.

Stress Relaxation Comparison by Larson-Miller Plot

Figure 15 utilizes the Larson-Miller parameter to compare the "envelopes" of stress relaxation curves for the various commercial groupings of beryllium copper alloys to demonstrate the relative behavior of these materials. For the high strength materials, peak age hardened Alloys 25 AT to HT and the special proprietary mill hardened Alloy 290 tempers TM02 to TM06, exhibit greater resistance to stress relaxation than the standard mill hardened Alloy 190 temper AM to XHMS. Particularly in the temperature range 125 C to 150 C, Alloy 290 temper TM02 to TM06 afford the greatest relaxation resistance of the high strength beryllium coppers. The high conductivity Alloy 3 and 174 exhibit relaxation resistance comparable to the high strength beryllium coppers over the temperature range 100 C to 150 C, and prove to be the most relaxation resistant of all the beryllium copper materials at more elevated temperatures up to at least 200 C.

Stress Relaxation in Other Copper Alloys

Isothermal stress relaxation plots comparing the stress relaxation behavior of other copper alloy spring materials to the beryllium coppers at 150 C and 200 C are shown in Figures 16 and 17, respectively. The inherently superior stress relaxation resistance of the heat treated copper alloys compared to those strengthened by cold working is readily apparent from these graphs.

HOW TO USE STRESS RELAXATION DATA IN SPRING DESIGN

Conductive springs designs for service at elevated temperatures must consider the consequences of stress relaxation to assure selection of a material that will maintain satisfactory spring force over the expected life of the connector. In typical signal connectors, where currents are low, resistance heating is minor and the principal concern is the ambient temperature of the enclosure in which the connector will operate. In power connectors, however, currents are high and temperature rise from resistance heating may be significant. Under these conditions, the expected temperature rise must be added to the normal ambient temperature to determine the operating temperature of the connector. Assume that a signal connector (no temperature rise concerns) is to be made in a flat cantilever beam configuration. A material not requiring heat treatment after forming is desired, e.g., a mill hardened beryllium copper or a cold worked copper alloy. In this example, assume further that strip thickness and maximum deflection are constrained to certain values. A design stress in the elastic region is specified, e.g., 75% of the

0.2% offset yield strength. The connector will be expected to operate at a temperature of, say, 150 C (300 F) and maintain a load of $W(\text{minimum})$ lb over a specified lifetime, e.g., 1000 hr. Beam length and width to produce the desired load are to be determined and a cost-effective material is to be selected.

The first step in the design process is to determine by how much the initial room temperature load must be increased to compensate for the expected stress relaxation in service:

$$W(\text{initial}) = W(\text{minimum}) / (\% \text{ Remaining Stress})$$

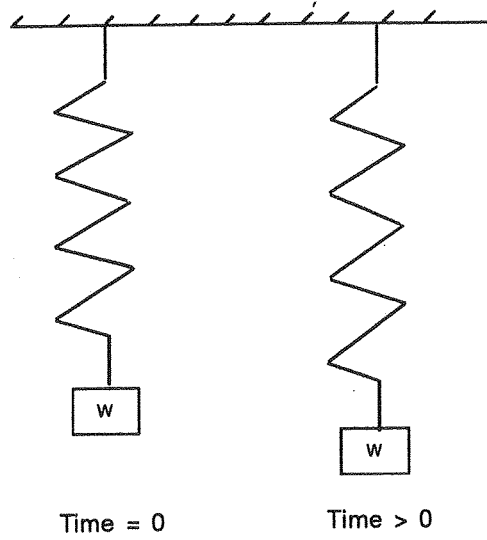
Obviously, the more resistant the selected connector alloy is to stress relaxation (larger % Remaining Stress), the smaller the compensation required in the room temperature load, $W(\text{initial})$. From Figure 11, Alloy 190 XHMS exhibits a remaining stress of about 85% after 1000 hr at 150 C. Similarly, C72500 and C52100 exhibit (Figure 16) remaining stress levels of 59% and 50%, respectively. $W(\text{initial})$ will thus range from $1.18W(\text{minimum})$ for 190 XHMS to $2.0W(\text{minimum})$ for C52100.

Next, determine the design stress (i.e., 75% of the 0.2% offset yield strength) from published mechanical property data such as shown in Tables I and II. The design stress will range from 129 ksi for 190 XHMS through 75 ksi for C52100 to as low as 66 ksi for C72500. Standard cantilever beam equations can then be employed to compute beam length (inversely proportional to the square root of the design stress) and beam width (directly proportional to $W(\text{initial})$ and to the cube of the length).

Shorter, narrower contact beams can be produced from alloys with higher design stress and better stress relaxation resistance. The smaller volume of premium performance material required per part can frequently offset apparent price advantages for less relaxation-resistant connector alloys.

If you require additional information or technical assistance, please contact Brush Wellman's Customer Technical Service Department at 216-486-4200. ■

Creep Constant Load



Stress Relaxation Constant Deflection

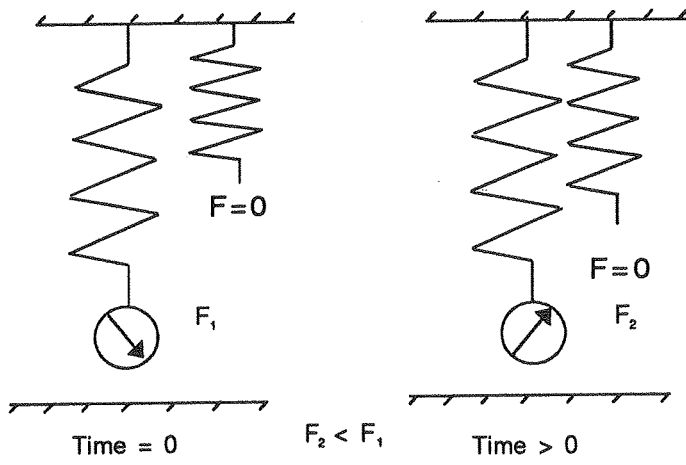
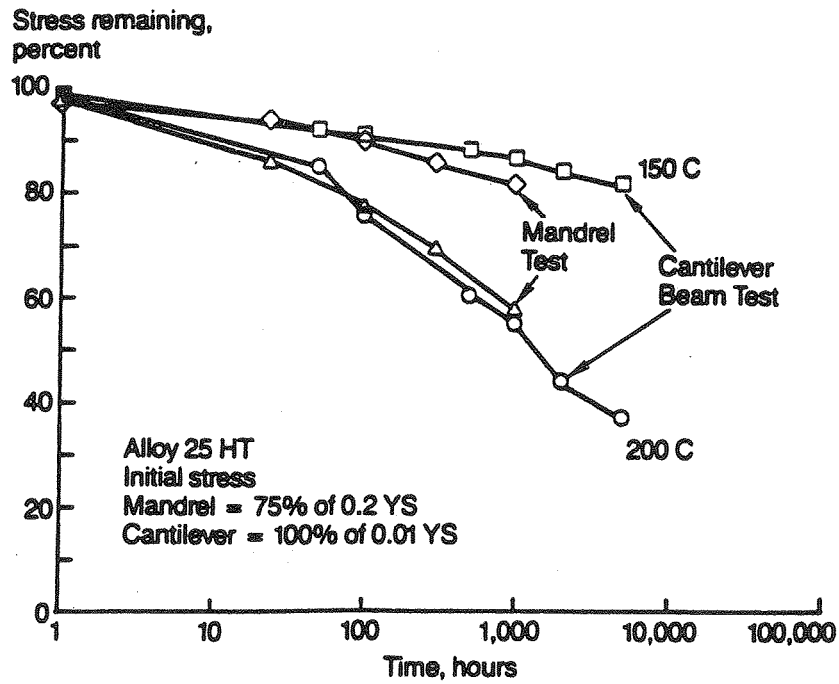
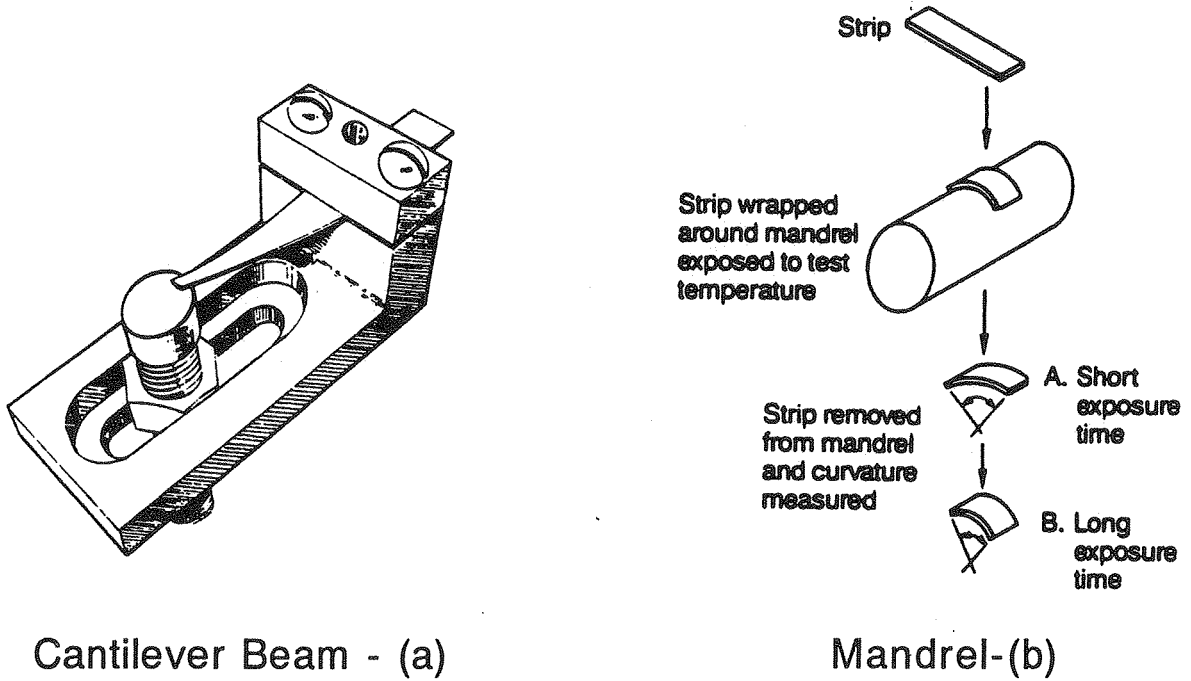


Figure 1

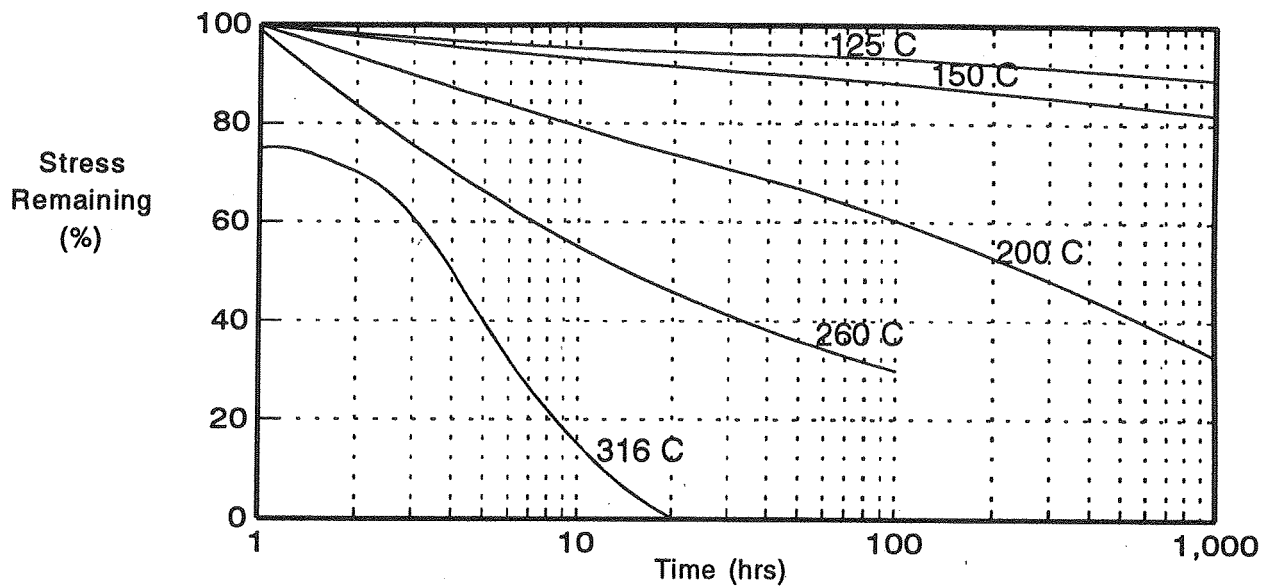
Comparison of Test Methods



**Cantilever Beam/Mandrel
Test Results - (c)**

Figure 2

Alloy 25 Stress Relaxation
Initial Stress = 100% of 0.01 YS
Isothermal - (a)



Isochronal - (b)

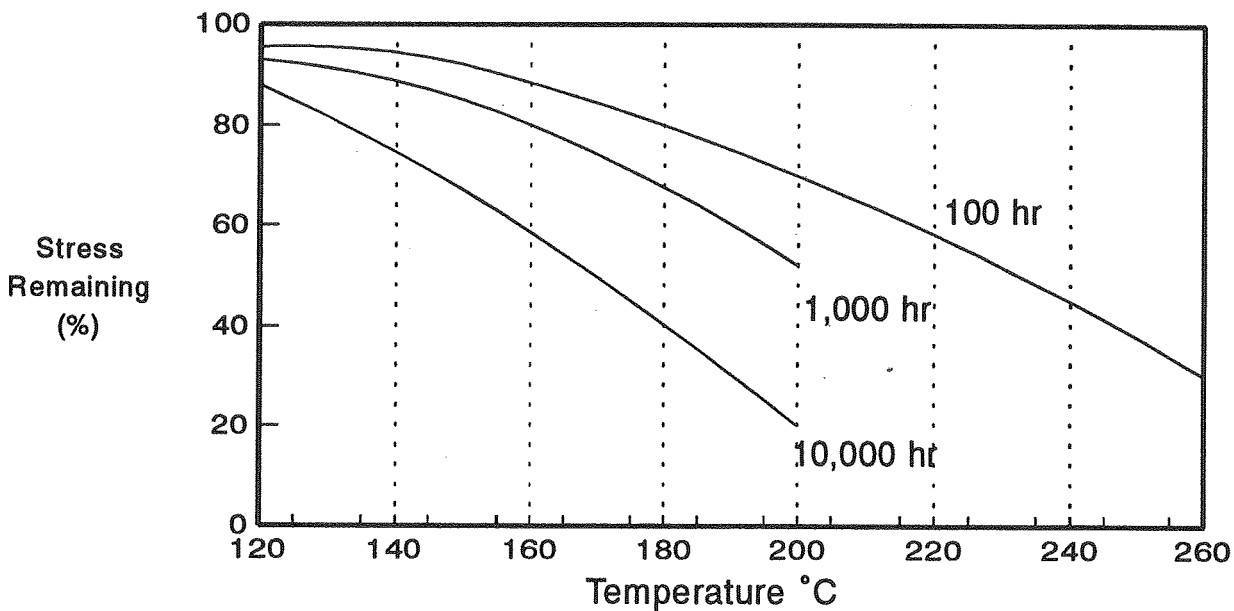
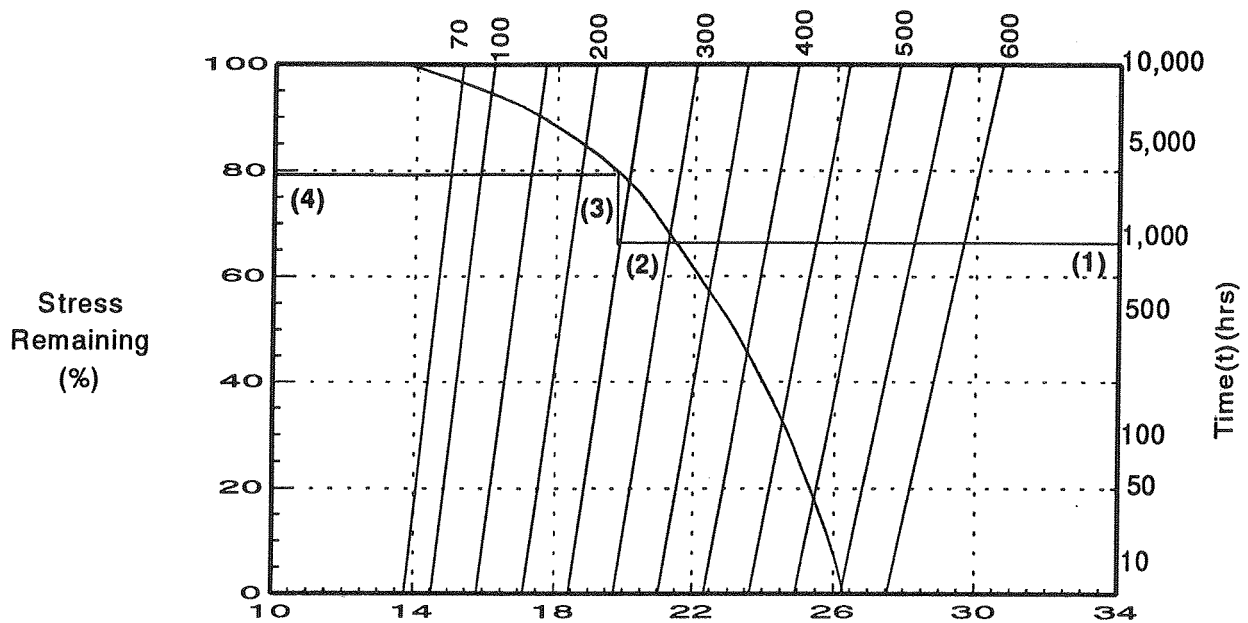


Figure 3

Larson-Miller Parameter - (c)

Temperature °F



$$\text{Larson-Miller Parameter} = \text{Temperature } (^\circ\text{R}) \times (25 + \log(t)) \times 10^3$$

The procedure to read this plot is: (1) select the accumulated exposure time along the right hand axis, (2) extend a horizontal line from this point to the exposure temperature line (the diagonal lines that are identified at top), (3) draw a vertical line from the time-temperature intersection point to the stress relaxation curve and (4) draw a horizontal line from this intersection to the left hand axis to determine the percentage of stress remaining after exposure. Example: 1,000 hrs exposure at 250°F produces a stress remaining of about 80%.

Figure 3 (Cont'd.)

Alloy 25 Stress Relaxation (all tempers) Initial Stress = 100% of 0.01 YS

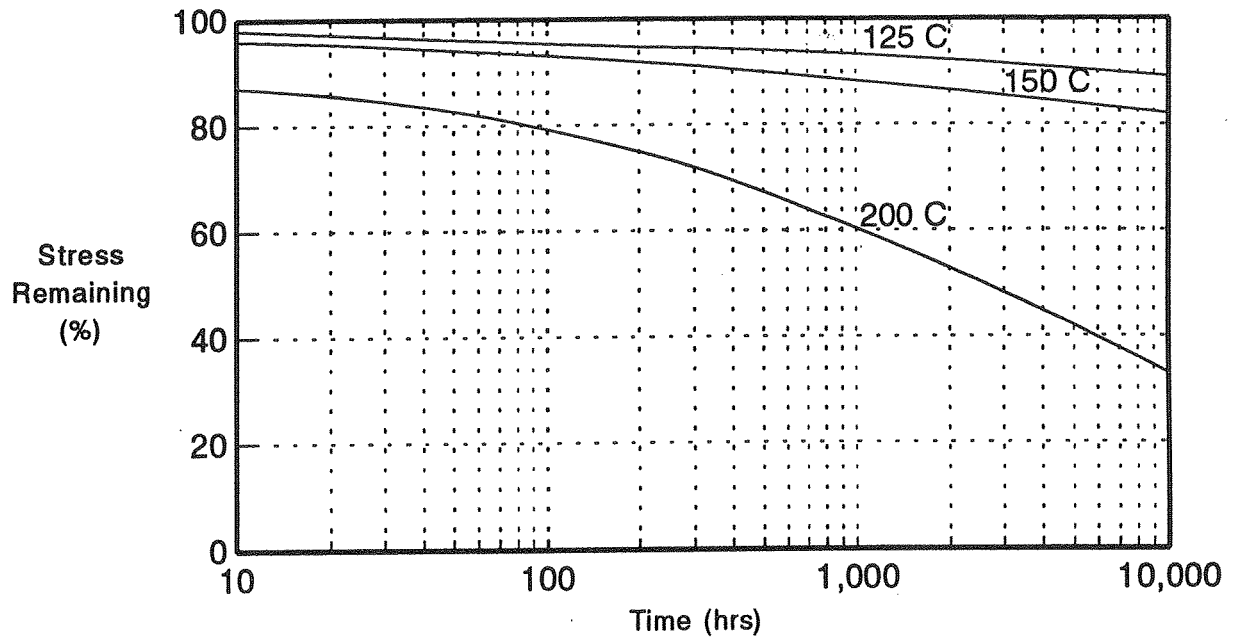


Figure 4

Alloy 25 Stress Relaxation Initial Stress = 100% of 0.01 YS

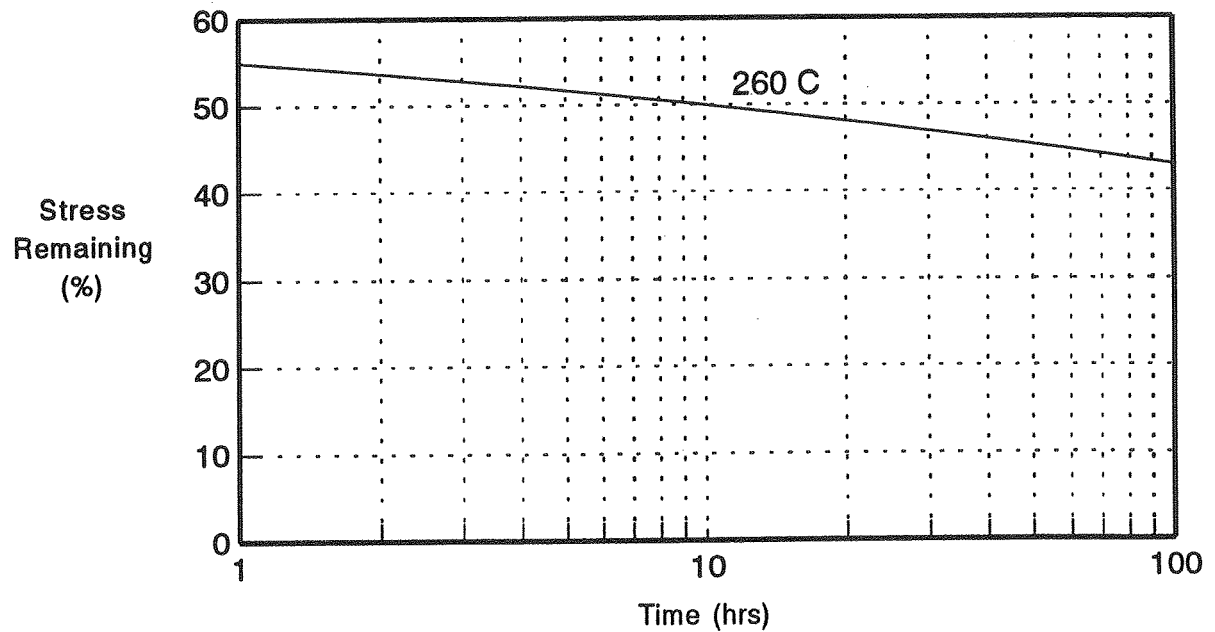


Figure 5

Alloy 25 Stress Relaxation Initial Stress = 100% of 0.01 YS

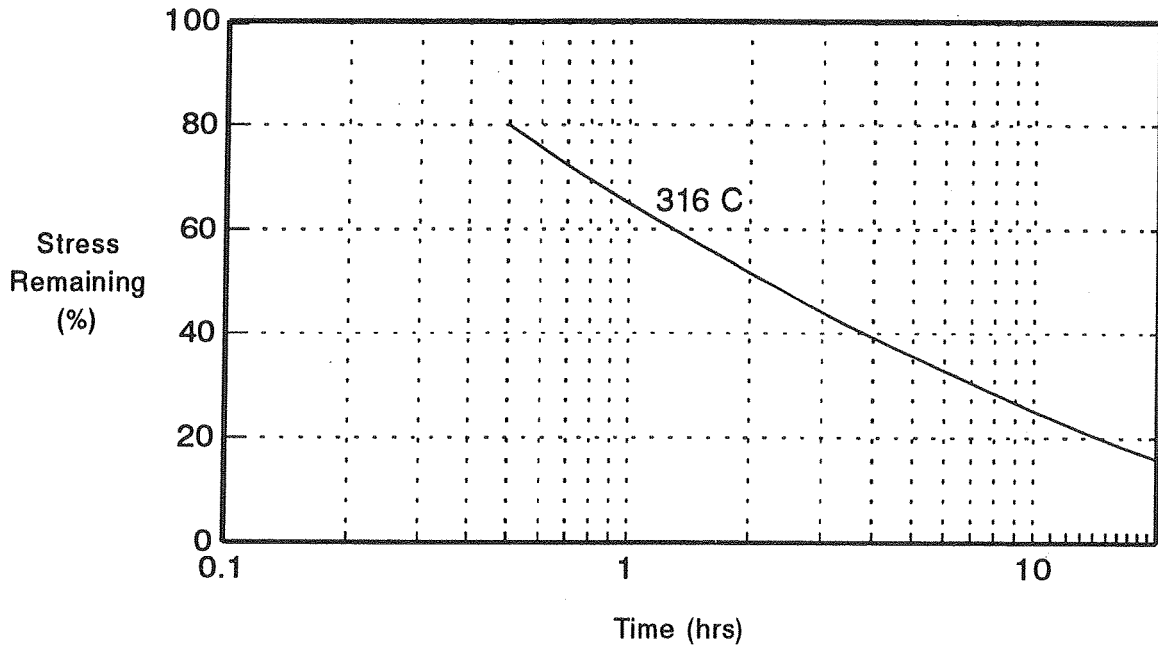


Figure 6

Alloy 190 Stress Relaxation (all tempers) Initial Stress = 100% of 0.01 YS

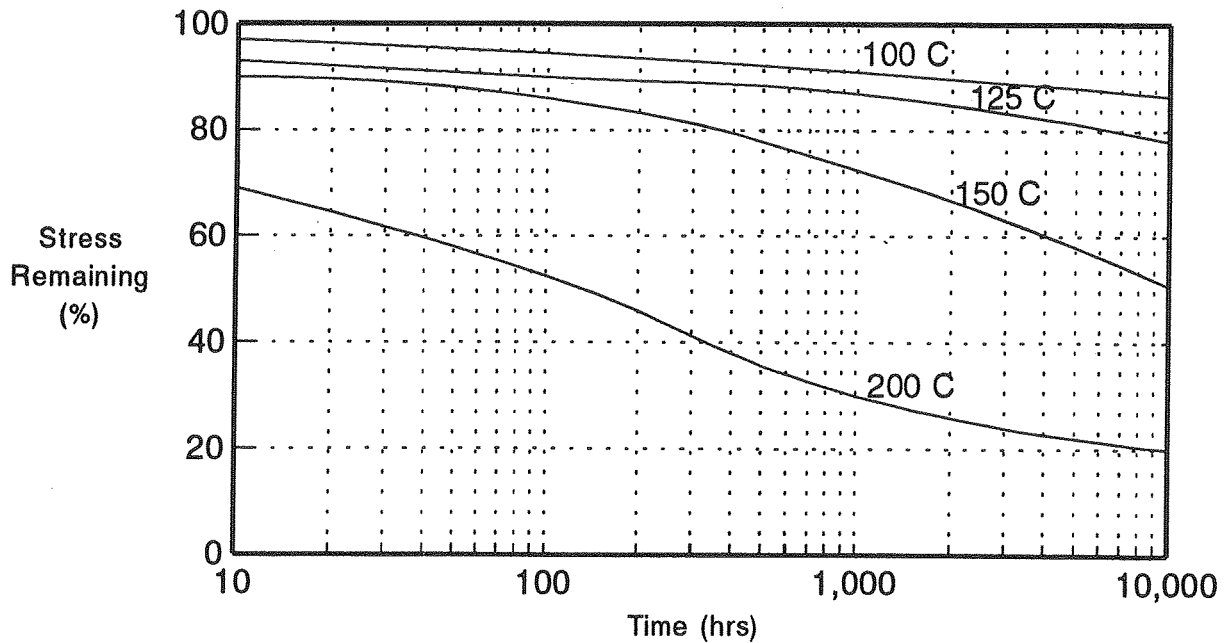


Figure 7

Alloy 190 Stress Relaxation (all tempers)
Initial Stress = 100% of 0.01 YS

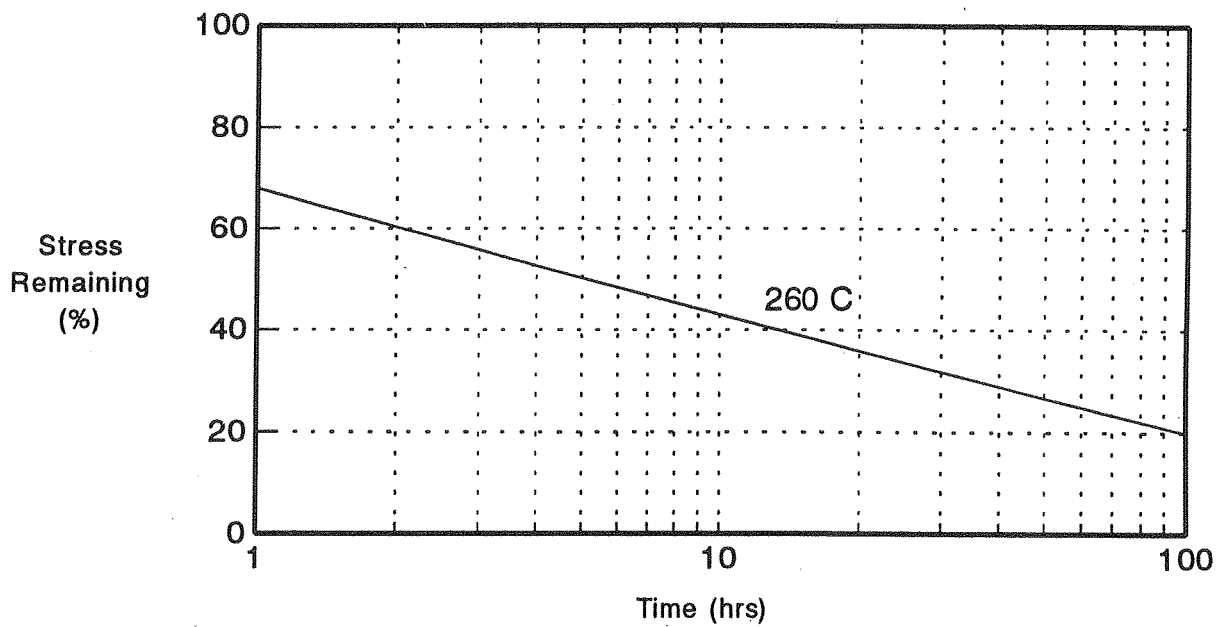


Figure 8

Alloy 190 Stress Relaxation (all tempers)
Initial Stress = 100% of 0.01 YS

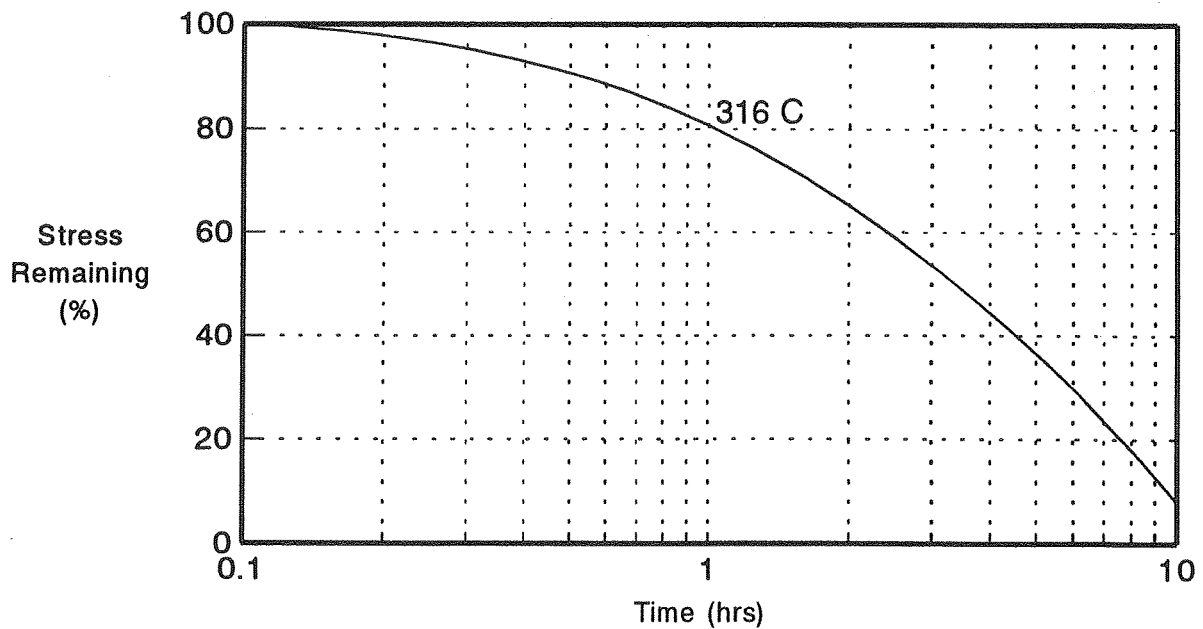


Figure 9

Alloy 290 Stress Relaxation (all tempers)
Initial Stress = 100% of 0.01 YS

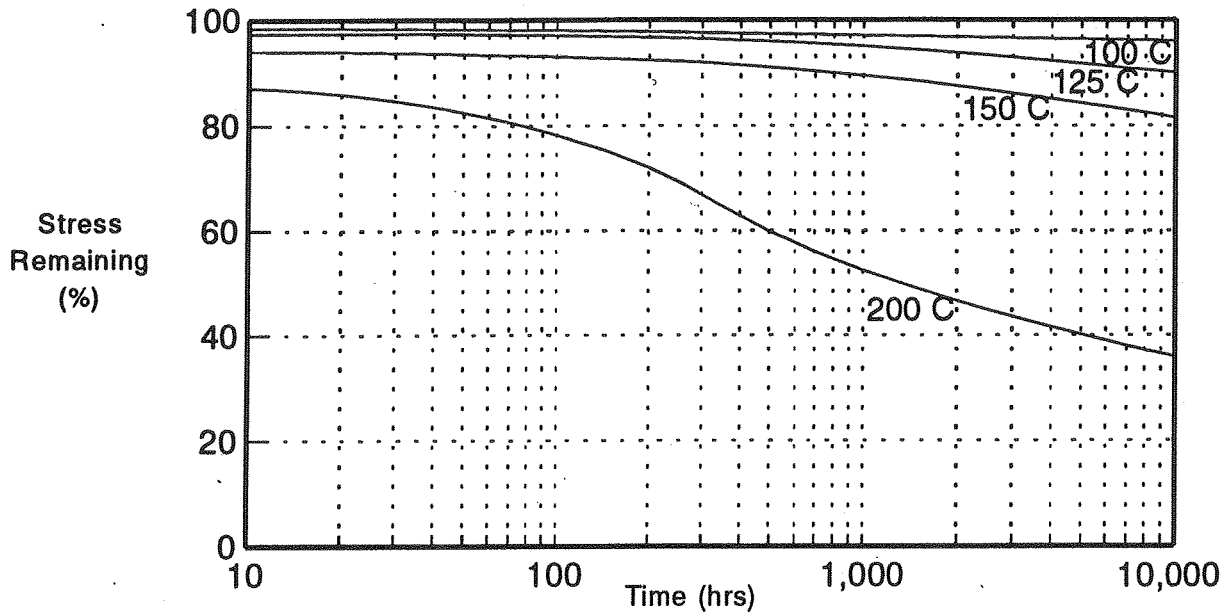


Figure 10

Alloy 3 Stress Relaxation (all tempers)
Initial Stress = 75% of 0.2 YS

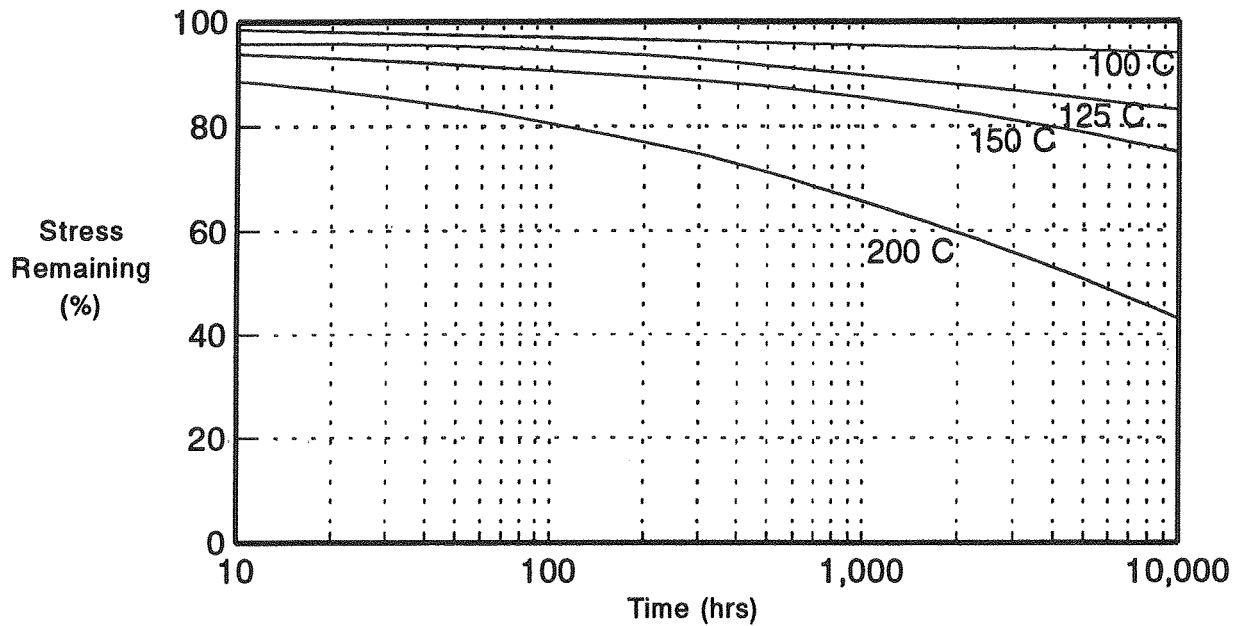


Figure 11

Alloy 174 HT Stress Relaxation

Initial Stress = 75% of 0.2 YS

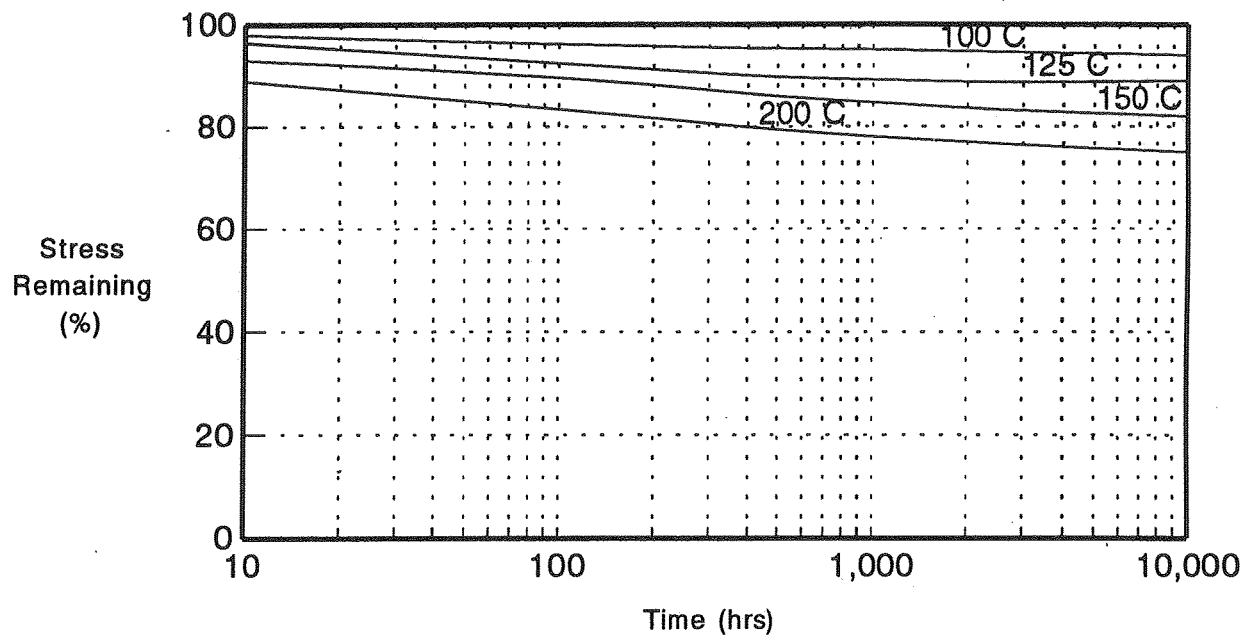


Figure 12

Alloy 190 Stress Relaxation (C17200 XHM)

Temperature 150 C

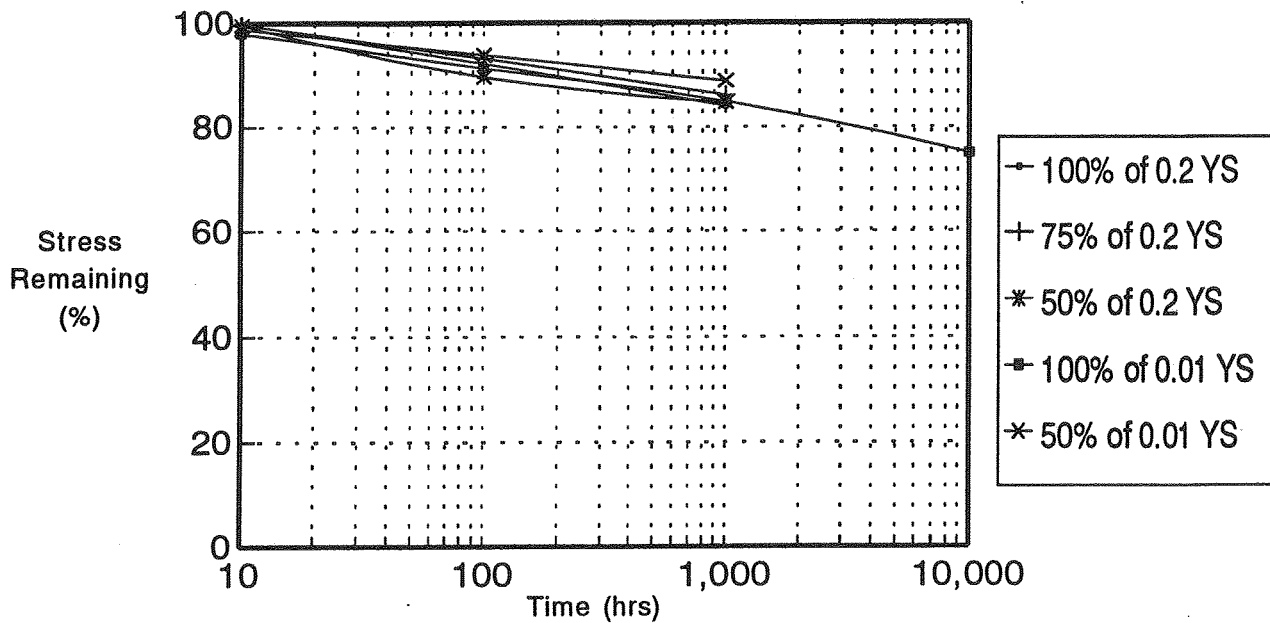


Figure 13

Alloy 174 Stress Relaxation (C17410 HT)

Temperature 150 C

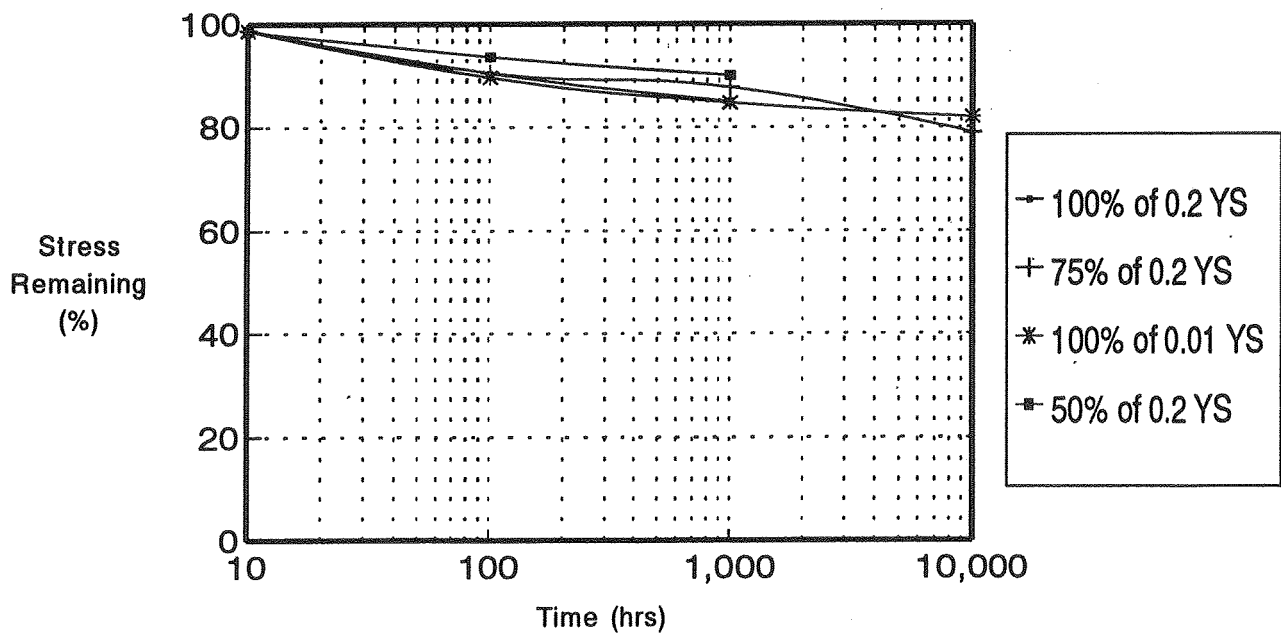


Figure 14

Comparison of Stress Relaxation Behavior Envelopes of Beryllium Copper Alloys

Initial Stress = 100% of 0.01% Y.S.
or 75% of 0.2 Y.S.

Temperature °F

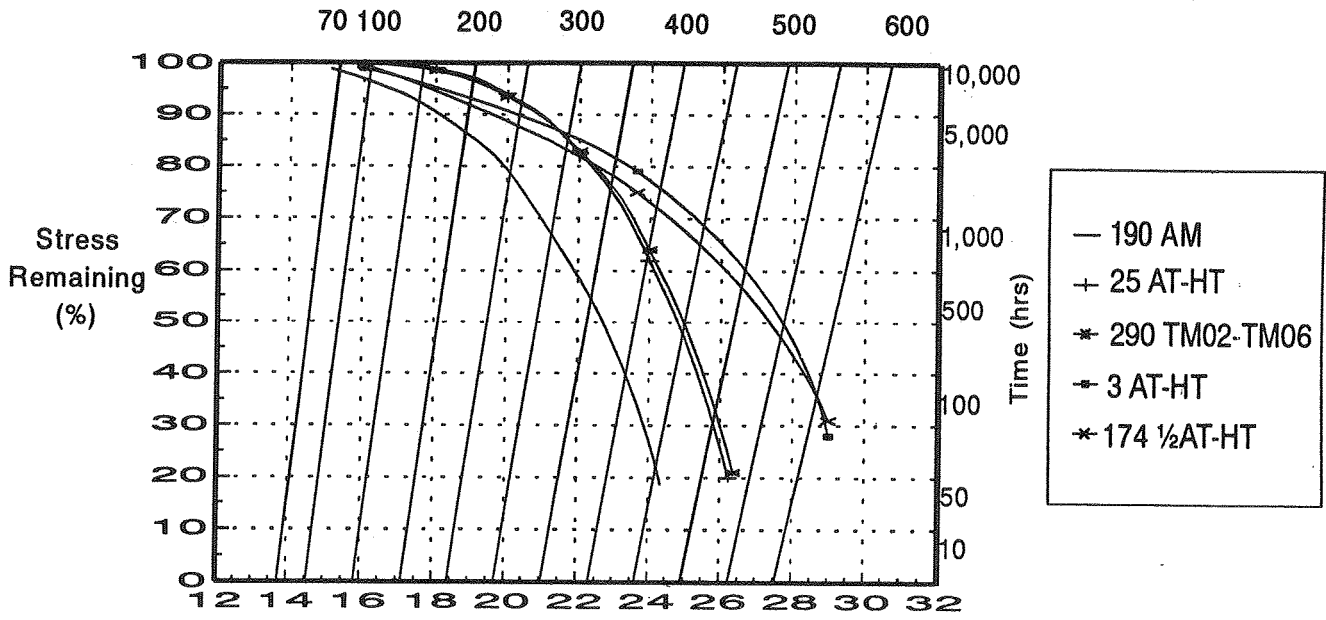


Figure 15

Stress Relaxation of Copper Alloys Temperature 150 C

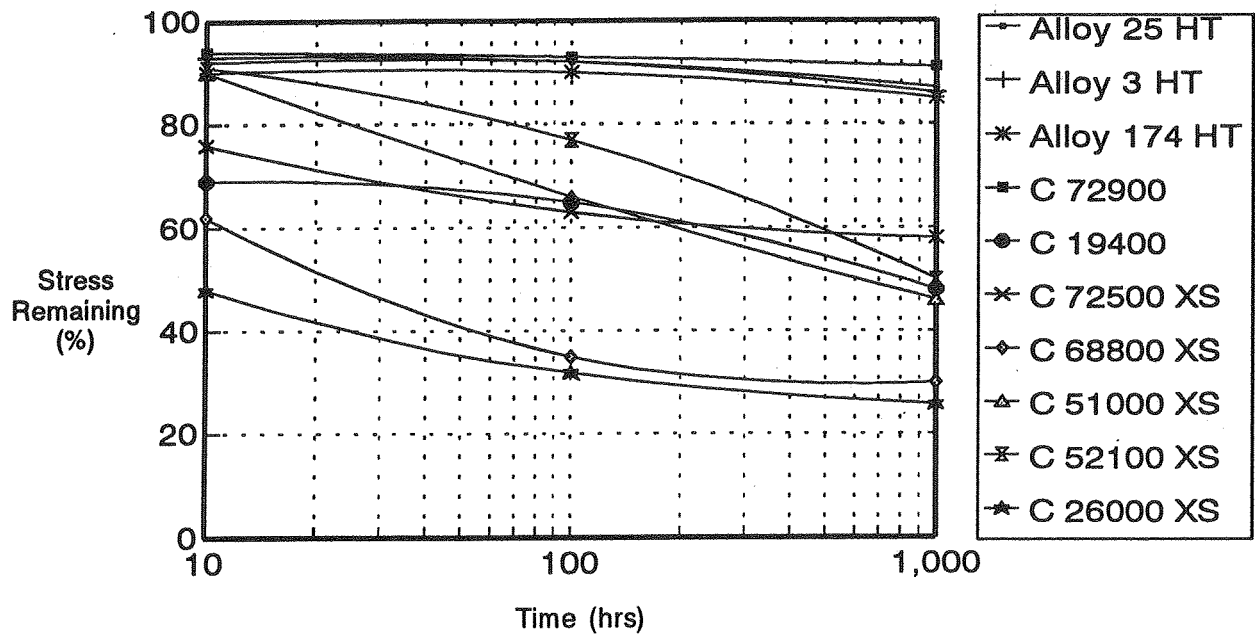


Figure 16

Temperature 200 C

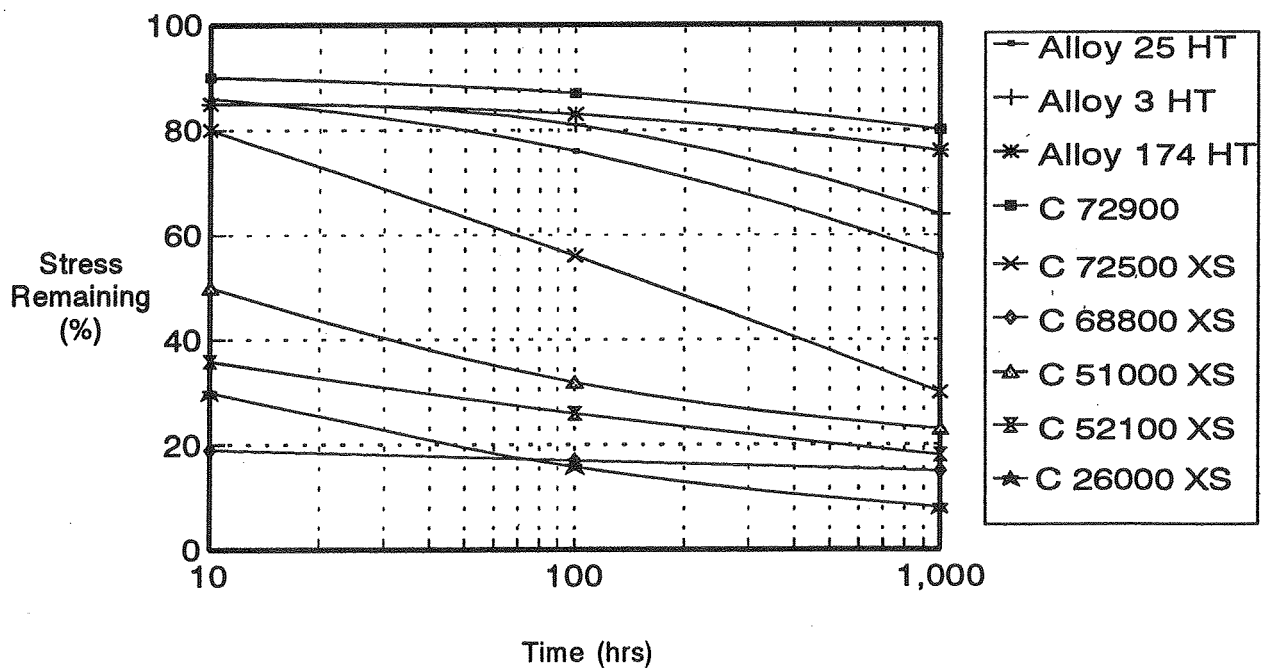


Figure 17

Table I
Properties of Beryllium Copper Strip Materials

Alloy/Temper		Nominal Composition (wt. %)	Yield Strength (ksi)	
			0.2% Offset	0.01% Offset
(C17200)	25 AT ^a	Co-Cu	152	101
	25 1/4 HT ^b	1.80-2.00	167	122
	25 1/2 HT ^b	0.20 Co+Ni	182	137
	25 HT ^b	0.60 Co+Ni+	188	139
(C17200)	190 AM ^c	Balance Cu	87	71
	190 1/4 HM ^c	"	90	71
	190 1/2 HM ^c	"	100	79
	190 HM ^c	"	122	95
	190 XHM ^c	"	155	117
	190 XHMS ^c	"	172	128
	(C17200)	290 TM02 ^c	"	118
	290 TM04 ^c	"	131	87
	290 TM06 ^c	"	137	92
(C17510)	3 HT ^c	0.5 Be-1.7 Ni-Cu	107	85
(C17410)	174 1/2 HT ^c	0.5 Be-0.5 Co-Cu	89	65
	174 HT ^c	"	112	90

^a = Aged 600°F/3 hours

^c = Proprietary Mill Hardening Treatment

^b = Aged 600°F/2 hours

Table II
Composition and Properties of Selected Copper Alloys

Alloy Temper	Nominal Composition (wt. %)	Yield Strength (ksi) 0.2% Offset
(C72900) - MH ^a	15 Ni8 Sn-Cu	80-135
(C19400) - Unknown	2.5 Fe-0.1 Zn-0.05 P-Cu	50- 75
(C72500) - XS	9 Ni-2 Sn-Cu	88-102
(C68800) - XS	3 Al-22.5 Zn-0..4 Co-Cu	117 min.
(C51000) XS	5 Sn-0.2 P-Cu	85-105
(C52100) XS	8 Sn-0.2 P-Cu	100-120
(C7025) -MH ^a	3 Ni-0.7 Si-0.2 Mg-Cu	65- 85
(C26000) - H	30 Zn-Cu	65- 80

^a = Mill Hardened

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