PROPERTIES OF BERYLLIUM COPPER C17510 FOR HIGH CONDUCTIVITY APPLICATIONS

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BRUSH WELLMAN
ENGINEERED MATERIALS

PAPER PRESENTED AT THE 30th ANNUAL RELAY CONFERENCE.

STILLWATER, OKLAHOMA   APRIL 27-28, 1982

Sponsored by: Oklahoma State University and The National Association of Relay Manufacturers

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ABSTRACT

This paper reviews the properties of beryllium copper Alloy C17510 employed in the manufacture of current-carrying springs in relays used for low-voltage, high-current applications. Specific data are given which compare the thermal, mechanical and electrical properties of this alloy at room temperature, and after elevated temperature exposure. In order to provide the designer with a comprehensive view of the alloy's performance, the paper also discusses the fabrication characteristics, bending fatigue strength and stress relaxation. Metallurgical characteristics that have led to the optimization of the alloy's performance are discussed.

INTRODUCTION

Due to the growing concern for product reliability, today's electronic components require materials that provide greater electrical and thermal conductivity, higher mechanical strength and improved resistance to stress relaxation in service. The trend toward miniaturization in the electronics industry has prompted the use of high strength copper alloys as the primary material for meeting design requirements for reliable mechanical properties. In addition, the need for a material with greater electrical and thermal conductivity particularly for high current applications has also become apparent. With the increase in the current carrying capacity of the switches, relays and electric terminals, temperature rise problems are encountered with materials possessing low electrical and thermal conductivity. Temperature rise has a deleterious effect on the spring contact performance for two reasons: first, it affects stress relaxation, which is strongly dependent upon the service temperature; second, the increase in the temperature causes the material to oxidize, thus altering the surface characteristics and increasing the contact resistance of the material.

Beryllium Copper Alloy C17510, developed by Brush Wellman to be an economical, high conductivity, moderately high strength copper alloy, offers the designer a high performance material. Development of Alloy C17510 was made possible through Brush Wellman's research effort to substitute less critical alloying elements as strengthening additions in high conductivity beryllium copper. In particular, the critical element most affected is cobalt which has been replaced by nickel in C17510.

To examine the properties in perspective, Table I compares the nominal mechanical, electrical and thermal properties of this alloy with other commercial copper alloy spring materials available in strip form. As shown in this Table, the most important feature of C17510 is that it combines reasonably high strength with superior electrical and thermal conductivity. This paper characterizes the alloy in detail for applications in switches and relays for high current circuits requiring high conductivity and high strength. Comparisons have been made with the cobalt-containing alloy C17500, a beryllium copper alloy of the same strength/conductivity regime of Alloy C17510.

TABLE I Comparison of C17510 with Copper Alloy Current-Carrying Spring Materials

Copper Alloy Number	Alloy Condition	Tensile Strength ksi	Yield Strength 0.2% Offset ksi	Elongation % in 2 in.	Modulus of Elasticity in Tension psi	Electrical Conductivity % IACS	Thermal Conductivity BTU/ft.hr°F
C17510	**Cold Rolled and Aged**	**120**	**110**	**12**	**20×10^6**	**50**	**144**
C17200	Cold Rolled and Aged	200	180	2	19×10^6	22	60
C17500	Cold Rolled and Aged	120	110	12	20×10^6	50	115
C19400	Spring	73	70.5	2	17×10^6	65	150
C19500	Spring	93	90	4	17×10^6	50	115
C51000	Spring	100	80	4	16×10^6	15	40
C63800	Spring	128	110	4	17×10^6	10	23
C64400	Cold Rolled Extra Spring and Aged	160	155	1	17×10^6	13	36
C65400	Spring	129	118	2	17×10^6	7	21
C68800	Spring	129	110	2	17×10^6	18	23
C72500	Spring	91	90	1	20×10^6	11	31

NOTE: Data compiled from published literature and/or Standards Handbook, Wrought Copper and Copper Alloy Mill Products, Alloy Data, Part 2, Copper Development Association, Inc., New York, NY, 1973.

HEAT TREATMENT AND METALLURGICAL CONSIDERATIONS

Alloy C17510 is a precipitation hardenable beryllium copper alloy containing nickel. This ternary alloy contains beryllium in the range of 0.2 to 0.6 weight percent, and nickel in the range of 1.4 to 2.2 weight percent. The high electrical and thermal conductivity of the alloy in conjunction with reasonably high mechanical strength are achieved through a two-stage heat treatment. This comprises solution annealing in the temperature range of 1650-1700 F (900-927 C) to ensure solid solution of the alloying elements, beryllium and nickel, followed by a rapid quench to retain this condition at room temperature. The alloy in this state is subjected to a precipitation hardening treatment in the temperature range of 850-900 F (455-482 C) to precipitate finely dispersed particles which strengthen the matrix and increase the conductivity as the alloying elements are effectively removed from the solid solution.

Heat treatment for C17510 can be designed to develop optimum combinations of strength and electrical conductivity. The yield strength normally reaches a peak value during the aging cycle, after which it diminishes as a result of overaging. Electrical conductivity, on the other hand, increases with increasing time and/or temperature during aging. Figure 1 shows typical aging response of C17510 strip, cold worked 21 percent prior to aging, and aged for 8 hours at temperatures ranging from 850-1050 F (454-566 C). This plot demonstates that depending on the choice of aging temperature, a wide range of strength and electrical conductivity with reasonable tensile elongation can be attained in C17510 in the precipitation hardened condition.

To provide the high strength and hardness along with maximum electrical and thermal conductivity the composition of Alloy C17510 is selected to optimize weight ratios between the alloying elements, nickel and beryllium. The ratio of nickel to beryllium is related to the stoichiometric amount necessary to form nickel beryllide (NiBe) such that during precipitation hardening, the precipitation reaction removes nickel and beryllium from the solid solution to provide high conductivity and a fine precipitate dispersion in the copper matrix.

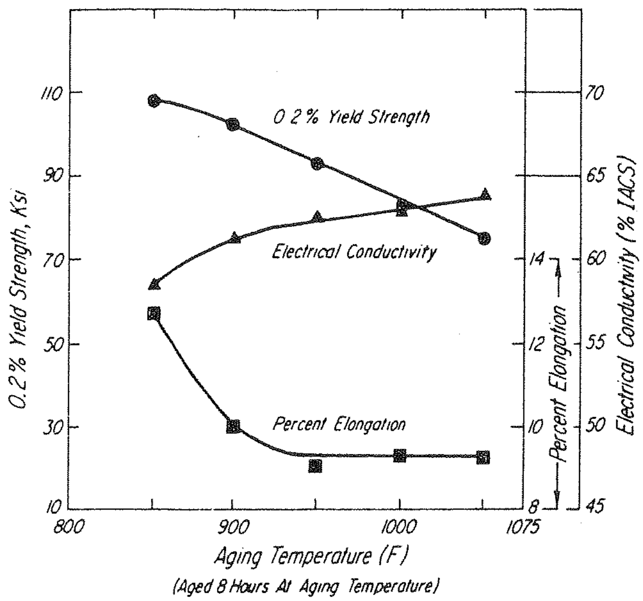

Figure 1 - Aging Response Curves for Alloy C17510 Strip (0.38 Be, 1.60 Ni, balance Cu), 0.016" thick, Cold Worked 21% Prior to Aging.

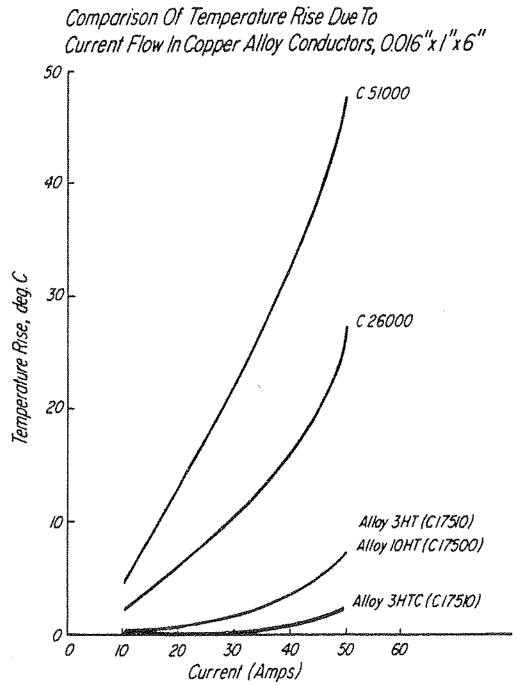

Figure 2 - Comparison of Temperature Rise due to Current Flow in Copper Alloy Conductors, 0.016" x 1" x 6".

PROPERTIES

Specific mechanical and physical properties of Alloy C17510 described in this section are intended to aid the designer with the selection of an optimum high conductivity, high strength alloy based upon performance. Other pertinent characteristics of this alloy are available from the trade literature[1] published by Brush Wellman. Applicable ASTM Standards were followed for the test procedures used to determine the special properties of this alloy.

Electrical and Thermal Conductivity

The electrical conductivity of a connector material has a direct influence on the temperature change of a current carrying conductor. Materials with the highest electrical conductivities yield the lowest temperature in a terminal while carrying a steady flow of current. To measure the temperature rise due to heat generated during the passage of current, tests were performed at various current levels for C17510 in ambient laboratory air. Comparison was made with C17500, and with other copper alloy spring materials, such as phosphor bronze and brass. Figure 2 plots the data indicating the temperature change due to current flow. For C17510 and C17500 in the HT (TH01) condition, the temperature change is not considered sufficient to cause any significant change in the spring properties of the material. The change in the temperature is even less for C17510 in the HTC condition[1], which combines high electrical conductivity (60% IACS minimum) with reasonable strength and good formability. On the other hand, the rise in the temperature in C51000 and C26000 should be sufficient to limit the current carrying capacity of these materials.

The electrical conductivity is inversely proportional to resistivity and is expressed as percent of the International Annealed Copper Standard or % IACS. The change in the resistivity of a conductor with rising temperature can be important in design of current carrying components. Figure 3 is a plot of the thermal conductivity and electrical resistivity of Alloy C17510 versus temperature in both the AT (TF00) and the HT (TH01) condition. There is a linear relationship with resistivity, i.e., the electrical conductivity diminishes with increasing temperature. The average temperature coefficient of resistance of C17510 in both the AT and the HT conditions defined as the rate of change in the resistivity per degree of temperature rise, generally expressed as ohms per ohm per degree Celsius[2], can be estimated to be 0.00202 at a reference temperature of 20 C (68 F). For copper of 100% conductivity the temperature coefficient of resistance is 0.00393[2].

The thermal conductivity of this alloy increases slowly and nonlinearly with rising temperature and is less dependent upon temperature than is the electrical conductivity. The excellent thermal conductivity of this alloy facilitates rapid heat transfer, which makes it ideal for applications as a precious metal contact support member in relays.

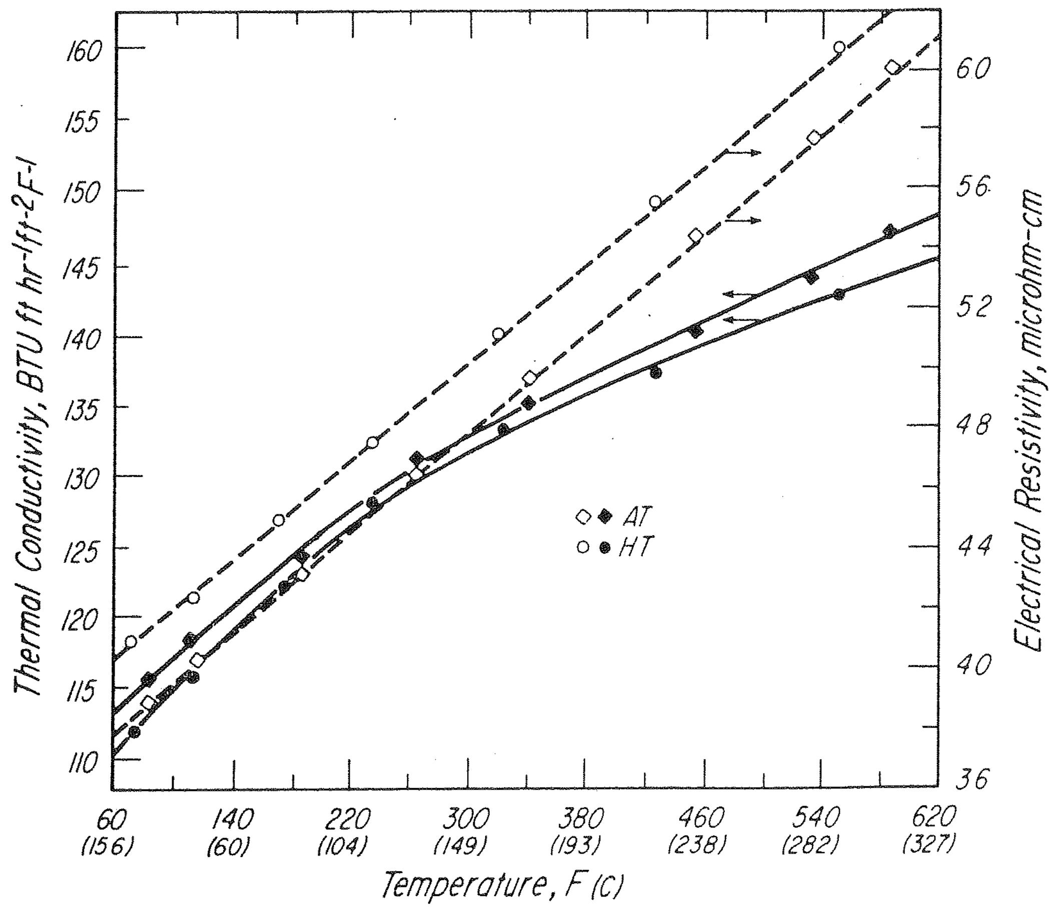

Figure 3 - Variation of the Thermal Conductivity and the Electrical Resistivity of Alloy C17510 with Temperature.

Mechanical Properties

Table II compares the mechanical properties of C17510 and C17500 in the precipitation hardened AT (TF00) condition at room temperature and at 300 F (149 C). The tensile properties of the two alloys are similar; the mechanical properties determined at 300 F (149 C) indicate excellent short term load carrying ability of the two alloys at higher operating temperatures.

TABLE II

Comparison of the Tensile Properties* of Alloy C17510 (0.38 Be, 1.53 Ni, balance Cu) and Alloy C17500 (0.54 Be, 2.51 Co, balance Cu) Strip in the AT (TF00) Condition.

Alloy	Test Temperature F(C)**	Tensile Strength ksi	Yield Strength 0.2% Offset ksi	Elongation % in 2 in.
C17510	70 (21)	121	94	15
	300 (149)			
C17500	70 (21)	116	89	16
	300 (149)	109	85	16

*Average of duplicate tests, longitudinal orientation.
**Tested in air after 10 min., exposure at temperature.

Stress Relaxation

Due to the importance of stress relaxation in current carrying springs, a detailed investigation has been conducted on the subject. The stress relaxation behavior of Alloy C17510 was studied by a method previously described[3]. Figure 4 plots the stress relaxation behavior of Alloy C17510 in strip form as a function of exposure time at temperatures 350 F (177 C), 450 F (232 C) and 600 F (316 C). Comparisons have been made with Alloy C17500 possessing tensile properties equivalent to Alloy C17510. The data were plotted as loss in stress, expressed as a percentage of the initial stress vs. the log of time. Assuming the permissible loss in stress as 25 percent of the initial value, both Alloys C17500 and C17510 appear to have adequate resistance to stress relaxation for temperatures as high as 350 F (177 C). The superiority of the nickel-containing version is evident from Figure 4. For example, as much as a 7 percent advantage is obtained after 100 hours at an operating temperature of 450 F. These alloys are used as current carrying springs where high operating temperatures up to 350 F (177 C) are expected.

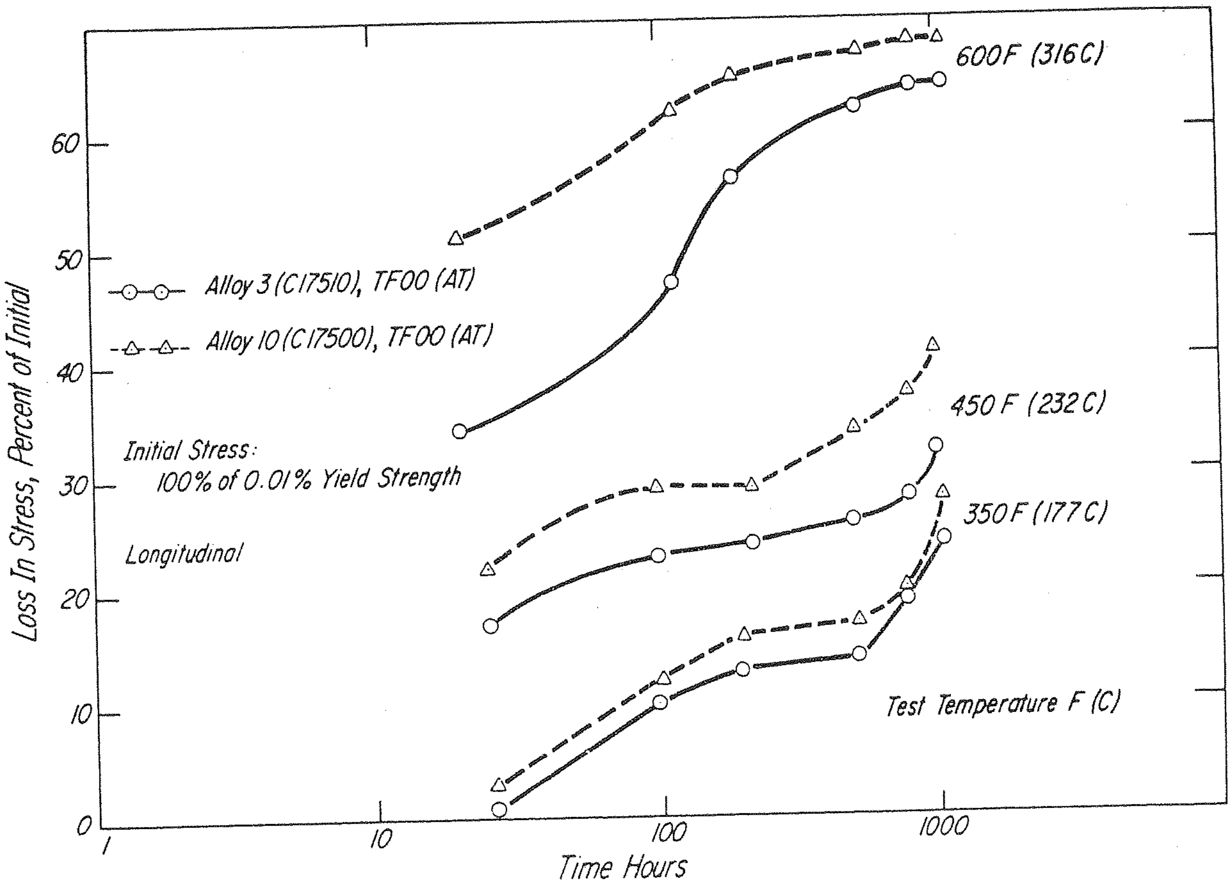

Figure 4 - Stress Relaxation Characteristics of Alloy C17510 Strip Compared to Alloy C17500 in AT Condition.

Fatigue

Fatigue properties of Alloy C17510 were evaluated in fully reversed bending to assess the performance of this alloy in sensitive switches and relays requiring repeated cyclical operations. Comparison has been made with the fatigue characteristics of C17500 strip at equivalent tensile properties. Figure 5 shows the results plotted as maximum bending stress versus the number of cycles of reversed fatigue loading. The data represent the first comparative investigation of the fatigue characteristics of the two alloys. At present, tests on additional heats and processing lots are underway to provide a statistically significant comparison of the fatigue life of the two alloys. The fatigue strength of C17510 is exceeded only by the high strength beryllium copper (C17200) noted for its outstanding fatigue strength[4]. Based on approximately equivalent yield strengths at 0.2% offset, C17510 compares favorably well with the other commercially available fatigue resistant copper alloy strip such as phosphor bronze (C51000), aluminum brass (C68800) and aluminum bronze (C63800). The high fatigue strength of C17510 strip recommends this material for cyclical operation such as in environments subjected to vibration.

Reverse Bending (R=-1) Fatigue Data of Alloy 3 (C17510) and Alloy 10 (C17500), HT Strip, 0.020" Thick, at Room Temperature (Run at 26 Hz in Model VSS-40 H Fatigue Testing Machine)

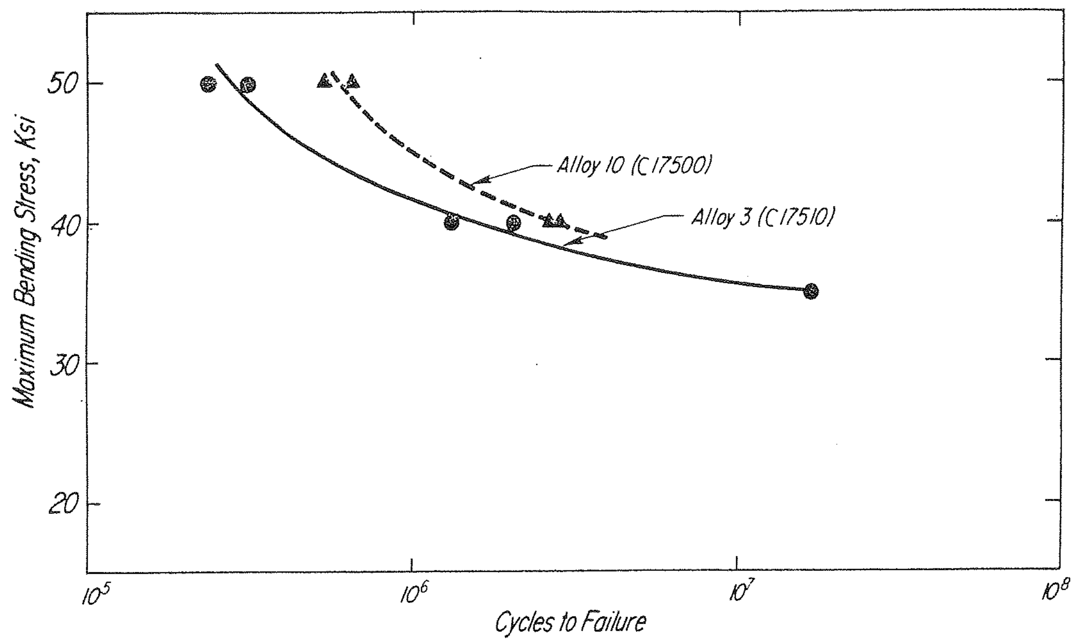

Figure 5 - Fatigue Curve of Alloy C17510 Compared to Alloy C17500 in Bending.

Fabrication

Finished parts or components can be easily formed from C17510 by most conventional metalforming processes. Table III compares the relative formability of this alloy in strip form with the C17500. Samples were bent 180° around pins with successively smaller radii until cracking occured on the tensile surface of the bend. The minimum bend radius, taken as the smallest radius which can be used without cracking, was expressed in multiples of strip thickness. The low directionality of the alloy permits design freedom and assures the most economical use of the material. No differences were observed in the formability of the two alloys.

Alloy C17510 can be joined by conventional techniques. Surface preparation, as with all copper based alloys, is critical for consistent production of high quality joints. The joining characteristics of 0.0114" C17510 strip in the AT (TF00) condition were evaluated and compared to C17500, in the same condition using brazing and soldering. Precleaning and fluxing prior to joining were employed to insure good wetting of the filler metal. Brazed joints were produced using silver-brazing alloys normally used with other copper alloys. The suitability of joining by soldering was evaluated using a 50 Sn-50 Pb filler metal. In both instances spreading of the filler metals was found to be uniform between the joints.

TABLE III

Results of Formability Test*

Alloy and Temper	Yield Strength, 0.2% Offset, ksi	Minimum Bend Radius, 180° Bend (multiples of strip thickness, t)
C17510 AT (TF00)	88	1.0 t
C17510 HT (TH01)	107	1.4 t
C17500 AT (TF00)	91	1.0 t
C17500 HT (TH01)	105	1.4 t

*Directions of bending normal to the rolling direction, average of tests from two heats.

APPLICATIONS

The advantages of beryllium copper Alloy C17510 include excellent electrical and thermal conductivity, high strength and improved resistance to stress relaxation at ambient temperatures ranging from room temperature to 300 F (149 C). This material, therefore, is extensively used in electrical switches and relays designed for high current applications.

CONCLUSIONS

Alloy C17510 offers the designer a high performance material that provides a unique combination of relatively high electrical and thermal conductivity and high strength. Conductive springs used in switches and relays made from this alloy can be upgraded because of the excellent electrical and thermal properties. Because of the high strength, components may be further miniaturized. High fatigue strength, resistance to stress relaxation and good forming characteristics make this alloy particularly suitable for many electrical applications. This material was originally developed to replace Alloy C17500 because of cobalt's critical situation. Comparative data presented in this paper demonstrate that Alloy C17510 can be used as a fully interchangeable, and less expensive, substitute for Alloy C17500. In the case of stress relaxation a clear superiority of C17510 is demonstrated.

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BIOGRAPHY

Dr. Amitava Guha is Senior Research Metallurgist in the Alloy Research and Development Department, Brush Wellman Inc., where he is engaged in materials development and the physical metallurgy of copper-base alloys. His MS and PhD degrees, both in Metallurgy, are from Carnegie-Mellon University and the University of Pittsburgh, respectively. Dr. Guha is a member of the ASTM Committee E28.10 on Standard Methods of Bend Testing for Spring Applications.

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