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PROPERTY INVESTIGATION OF COPPER BASE ALLOYS AT AMBIENT AND ELEVATED TEMPERATURES

Dennis D. Horn and Henry F. Lewis

ARO, Inc.

July 1965

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FOREWORD

The research effort reported herein was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC) under Program Element 62410034/7778, Task 777805, and monitored by DCS/Plans and Technology.

The research study presented was conducted by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1000. The research was performed under ARO Project No. PL2289, and the manuscript was submitted for publication on March 9, 1965.

Many materials compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

This technical report has been reviewed and is approved.

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ABSTRACT

An investigation was made to determine the properties of copper base alloys at room and elevated temperatures for high heat flux applications. Literature surveys were conducted to study the properties of copper-beryllium, copper-zirconium, and other commercial grades of copper and copper alloys. These properties were compared with experimental data for copper-zirconium and two alloys of copper-beryllium at temperatures up to 1000°F. The test data indicated that the copper-beryllium alloys can be obtained in large sizes with strength levels comparable to survey property levels, whereas for copper-zirconium it was more difficult to reach tabulated strengths because the effectiveness of cold working was reduced for large size billets. The final selection of an alloy depends upon the requirements of a specific application.

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NOMENCLATURE

E	Modulus of elasticity, psi
k	Thermal conductivity, Btu-in./sec-ft^2-°F
R_b	Rockwell hardness (B scale)
α	Coefficient of linear expansion, 1/°F
ν	Poisson's ratio

ABBREVIATIONS

Ag	Silver
AT	Annealed and heat treated
Be	Beryllium
Co	Cobalt
Cr	Chromium
Cu	Copper
CW	Cold worked
Elong	Elongation
ETP	Electrolytic tough pitch
HT	Work hardened and heat treated
psi	Pounds per square inch
R of A	Reduction of area
Zr	Zirconium

SECTION I
INTRODUCTION

An investigation of the physical properties of copper base alloys was conducted to obtain design information for a backside water-cooled nozzle liner (Ref. 1) to use in the calibration of an electric arc heater. Property data were essential to assist in the selection of a nozzle material for this high heat flux application. The choice of materials was previously narrowed to the copper base alloys, primarily to take advantage of the high thermal conductivity these alloys exhibit (Ref. 1).

A survey of the literature was conducted to assemble data from many sources on various alloys of copper-beryllium (Cu-Be), copper-zirconium (Cu-Zr), copper-chromium (Cu-Cr), and commercial copper, both electrolytic tough pitch (ETP) and oxygen-free grades. The experimental portion of the investigation consisted of tensile tests at ambient and elevated temperatures. The necessity for obtaining these data arose because a billet of 3-in. diameter was required to fabricate a nozzle liner, and virtually all handbook property data were given for strip or small diameter wire or rod specimens. Uncertainties therefore existed as to the actual strength obtainable in the large billet sizes, particularly for alloys requiring considerable cold work for quoted strength. The elevated-temperature tests were of prime importance because of lack of extensive handbook data.

Three alloys were tested: copper-beryllium (Cu-Be) Alloy 10, (Cu-Be) Alloy 50, and a copper-zirconium (Cu-Zr) alloy. Accordingly, nominal 3-in.-diam billets of each alloy were purchased and machined into test specimens. The Cu-Be alloys were purchased in the annealed and heat-treated (AT) condition, and Cu-Zr was cold worked as severely as the forging equipment of the supplier would permit. Testing was carried out at the Metallurgical Laboratory, Engineering Support Facility (ESF), Arnold Engineering Development Center.

SECTION II
PROPERTIES OF COPPER-BERYLLIUM ALLOYS

The beryllium alloys of copper have the highest strength of any of the copper base alloys. The Cu-Be alloys are generally considered for use in high heat flux applications since these alloys have strengths comparable to steel while exhibiting thermal conductivities as high as 30 to 70 percent of pure copper. The wrought Cu-Be alloys can be divided into two general types: (1) the high strength alloys and (2) the high conductivity alloys.

The high strength alloys usually contain between 1.5- and 2.2-percent Be, whereas the high conductivity alloys contain between 0.25- and 0.70-percent Be. The physical and mechanical properties from both alloy groups are presented.

2.1 HIGH STRENGTH ALLOYS

Alloys 25 and 165 are two major types of high strength wrought Cu-Be, Alloy 25 being the most widely used. The following table shows the chemical composition of these alloys.

Chemical Composition of High Strength Cu-Be Alloys

Alloy	Beryllium	Cobalt	Copper
25	1.80 - 2.05%	0.20 - 0.35%	Balance
165	1.60 - 1.80%	0.20 - 0.35%	Balance

Information from several sources about the engineering properties is presented in Table I. The form of the material, that is, rod, bar, strip, wire, or billet, may have a considerable influence on the strength, and therefore the form is noted where information was available. Cu-Be alloys derive their high strength principally from heat treating or age hardening. The alloys considered here are in (1) the AT condition and (2) the HT condition. Table I shows that only small gains in strength can be obtained by cold working Cu-Be.

Values of thermal conductivity, linear coefficient of thermal expansion, and Poisson's ratio are not generally determined in a standard materials laboratory; therefore little data were available for these properties. It is assumed that these properties remain constant for all forms and heat treatments of the material. The thermal conductivity for Alloy 25 at temperatures to 400°F is shown in Fig. 1. The conductivity increases with temperature from 0.22 Btu-in./sec-ft^2-°F at 50°F to 0.27 at 400°F (Ref. 4).

The elevated-temperature strength data on Alloy 25 are presented in Fig. 2. In all cases the strength decreased slowly with increasing temperature up to 500°F. Above 500°F a rapid reduction in strength resulted. The elongation and modulus of elasticity at temperatures up to 1000°F are shown in Fig. 3. The elongation slowly decreased from room temperature levels to a low value of approximately 2 percent at temperatures from 500 to 600°F for both the AT and HT conditions, which indicated this material to have relatively low ductility at these temperatures. The modulus of elasticity of Alloy 25 decreased rapidly above 500°F and at 1000°F was less than 5 x 10^6 psi for the AT and HT conditions.

2.2 HIGH CONDUCTIVITY ALLOYS

Among the Cu-Be alloys in this category, Alloys 10 and 50 are probably the most common. The compositions of the two alloys are similar, the primary difference being a substitution of silver for part of the cobalt in Alloy 50. The composition of these alloys is presented in the following table.

Chemical Composition of Cu-Be High Conductivity Alloys

Alloy	Beryllium	Cobalt	Silver	Copper
10	0.45 - 0.60%	2.35 - 2.60%	---	Balance
50	0.25 - 0.50%	1.40 - 1.70%	0.90 - 1.10%	Balance

The engineering properties of the high conductivity alloys at room temperature are presented in Table II for the AT and HT conditions. The tabulated data indicate that AT billets have strengths about 10 to 20 percent lower than the strip or bar stock, since the large size of billets generally precludes uniform heat treatment. The high conductivity alloys, when compared with the high strength alloys of Table I, showed about 40-percent decrease in strength but sizable increases in ductility and thermal conductivity. The modulus of elasticity and linear coefficient of thermal expansion are about the same for both groups of alloys.

The strength and elongation at elevated temperatures of Cu-Be Alloy 10 in the AT condition are presented in Fig. 4. The strength decreases rapidly from 400 to 600°F, whereas the elongation reduces sharply at temperatures above 500°F. The extremely low elongation above 500°F indicates that Alloy 10 exhibits hot brittleness in this temperature regime.

Thermal conductivity data at elevated temperatures to 400°F for Alloy 50 are shown in Fig. 1. The conductivity can be seen to increase slowly as the temperature rises. These data represent typical values of conductivity expected for this alloy but do not account for small variations which may be caused by heat treatment, form, and size effects.

SECTION III
PROPERTIES OF COPPER-ZIRCONIUM ALLOY

The primary type of Cu-Zr alloy considered for nozzle material consists of a high purity copper which is oxygen free and contains from 0.13- to 0.15-percent zirconium. This alloy has a thermal conductivity from 90 to 95 percent that of pure copper. The Cu-Zr is used in high heat flux applications because of its high thermal conductivity and reasonably high strength at elevated temperatures. Table III presents some of the available property data for Cu-Zr at room temperature. Ultimate strengths of 60,000 psi and yield strengths of 50,000 psi are typical values expected from Cu-Zr. However, the strength depends to a large extent upon the size and the shape of the piece needed, that is, sheet, rod, and billet. Nozzle applications may require sizes which will not allow the tabulated strength values to be actually obtained.

The strength of Cu-Zr is derived primarily from cold working the annealed alloy. The effect of cold working on Cu-Zr alloy is shown in Fig. 5. It can be seen that the yield and ultimate strengths increase rapidly for amounts of cold working up to 40 percent; above this amount the cold working is less effective, but the strength continues to increase slowly. However, the elongation decreases rapidly for amounts of cold work up to 40 percent and remains reasonably constant with additional cold working.

An additional 10- to 15-percent increase in strength is obtained by age hardening. This is accomplished by reheating the cold-worked alloy from 700 to 800°F for approximately 1 hr. Age hardening Cu-Zr in this manner increases its electrical conductivity by about 30 percent. For most metals, electrical and thermal conductivities follow roughly parallel paths, so it may be tentatively concluded that the thermal conductivity is also increased by age hardening, although no experimental data are available for Cu-Zr to support this conjecture.

The elevated-temperature data taken from Ref. 10 are plotted in Fig. 6. The reduction of area and ultimate strength of Cu-Zr (0.15 percent Zr) for temperatures from ambient to 1100°F is presented for 54- and 84-percent cold-worked alloys. The ultimate strength decreases slowly with temperatures to 600°F and then decreases rapidly for temperatures above 600°F for both materials. For temperatures from ambient to 800°F the 84-percent cold-worked alloy has strength from 5000 to 8000 psi higher than the 54-percent alloy.

The percent reduction of area at elevated temperature is also presented in Fig. 6 for the 54- and 84-percent cold-worked alloys. The area reduction for both alloys decreases 6 to 8 percent from ambient to 500°F and then increases slowly as the temperature is increased above 500°F. The 54-percent alloy exhibits greater area reduction, as would be expected. Both alloys maintain a high level of ductility throughout the elevated-temperature range.

Other properties at elevated temperature which are significant include 0.2-percent yield strength, percent elongation, and modulus of elasticity. Numerical values for these properties are presented in the following table (from Refs. 8 and 10) at temperatures of 750, 930, and 1110°F for 0.25-in.-diam Cu-Zr rod specimens cold worked to 54 and 84 percent.

Cold Worked, percent	Test Temperature, °F	0.2-percent Yield Strength, psi	Elongation, percent	Modulus of Elasticity, psi
54	750	39,000	9.0	17.0×10^6
	930	28,000	9.0	15.4×10^6
	1110	17,700	10.0	14.6×10^6
84	750	45,000	9.0	15.7×10^6
	930	25,800	9.0	16.9×10^6
	1110	-	64.0	14.8×10^6

At 750°F the yield strength for the 84-percent alloy is 6000 psi higher than the 54-percent alloy. However, the strength decreases more rapidly for the 84-percent alloy than for the 54-percent alloy at temperatures above 750°F. This trend parallels that shown in Fig. 6 for the ultimate strength.

The thermal conductivity at elevated temperatures is indicated in Fig. 1. The conductivity remains constant for all temperatures shown. The availability of thermal conductivity data is highly limited, and values presented should be used with extreme caution.

SECTION IV
PROPERTIES OF MISCELLANEOUS COPPER BASE MATERIALS

Several additional materials, some containing small amounts of alloying elements in copper, have high thermal conductivities and may be considered for high heat flux applications. These materials include electrolytic tough pitch copper, copper-sulphur, leaded copper, copper-chromium, oxygen-free copper, copper-tellurium, and copper-phosphorous. Of these, only electrolytic tough pitch (ETP) copper, copper-chromium (Cu-Cr), and oxygen-free copper are considered in this report.

4.1 COPPER-CHROMIUM

The most common alloy of copper and chromium in the copper rich alloys is a binary alloy containing from 0.70- to 0.80-percent chromium and the balance copper. As with Cu-Zr, its strength is derived from cold working and precipitation hardening. The room temperature properties which may be attained by cold working to small diameters and heat treating are presented in the following table.

Alloy	Ultimate Strength, psi	0.5-percent Yield Strength, psi	Elongation, percent	k	Ref.
99% Cu, 0.77% Cr, 0.015-in.-diam wire	75,200	67,800	23.5	-	12
99% Cu, 0.85% Cr, rod	70,000	60,000	20	0.62	13

While the strength of Cu-Cr is higher than Cu-Zr at room temperature, the thermal conductivity is slightly lower because of the greater percentage of alloy material in Cu-Cr.

The elevated-temperature properties of Cu-0.70-percent Cr are shown in Fig. 7 for a 0.25-in.-diam rod. The ultimate strength decreases by an average of 4000 psi for each 100°F temperature rise up to 800°F. Above 800°F the strength decreases rapidly to the annealed level. The percent reduction of area, a measure of material ductility, is also presented as a function of test temperature in Fig. 7. At temperatures below 900°F the reduction of area decreases as the temperature increases. Above 400°F the decrease is rapid, indicating a hot brittleness condition in the alloy. Above 1000°F the annealing action allows the material to become more ductile.

4.2 ELECTROLYTIC TOUGH PITCH COPPER

Electrolytic tough pitch (ETP) copper is a commercial grade of copper (99.9-percent Cu) with approximately 0.04-percent oxygen. The oxygen results from the elimination of impurities in the refining process. This material exhibits high thermal conductivity and compares favorably with pure copper as shown in Fig. 1. The room temperature mechanical properties are presented in Table IV. The ultimate and yield strength values of ETP copper in the cold-worked condition are high enough for use in high heat flux applications.

The elevated-temperature yield strength and modulus of elasticity are shown in Fig. 8 for 84-percent CW and 50-percent CW ETP copper, respectively. The yield strength remains above 40,000 psi for test temperatures up to 300°F. However, at temperatures above 300°F the strength decreases rapidly to the annealed strength level at 500°F. The modulus of elasticity decreases steadily as the test temperature is increased above room temperature. These temperature properties of ETP copper made the use of this material undesirable for elevated-temperature applications. However, it is satisfactory for use in highly cooled, high heat flux conditions because of its high thermal conductivity and high room temperature strength.

4.3 OXYGEN-FREE COPPER

Oxygen-free copper is characterized by refining under a controlled atmosphere which minimizes the presence of oxygen in the copper. The oxygen-free copper thereby has more ductility than electrolytic tough pitch copper and is less susceptible to hot brittleness when subjected to reducing atmospheres at elevated temperatures. Otherwise, the mechanical properties of oxygen-free copper are very similar to other high conductivity coppers.

The room temperature properties of oxygen-free copper are presented in Table V for several forms in the cold-worked condition. In general, the tensile properties are similar to ETP copper. The reduction of area in tensile tests of oxygen-free copper range from 86 to 91 percent for the cases indicated in Table V. Yield strengths range from 29,400 to 66,000 psi for various forms and degrees of cold work. These strengths are in the usable range for high heat flux applications.

While no data are presented for properties at elevated temperatures, the estimated temperature limit is from 300 to 500°F. Above this temperature range the amount of annealing becomes appreciable, and the strength is reduced.

SECTION V
TENSILE TEST PROGRAM

A test program was conducted to determine experimentally the mechanical properties of the various copper alloys previously discussed. The test specimens were machined from material samples of the size range necessary to fabricate various nozzle shapes and components for high heat flux applications. The test results are therefore representative of the best mechanical properties which can reasonably be obtained with fabricated hardware rather than the properties of cold-drawn wire often listed for these materials. The tensile tests were conducted at both room and elevated temperatures to 1000°F. The tests were performed by the Chemical and Metallurgical Branch, ESF.

5.1 DESCRIPTION OF BILLETS AND TEST SPECIMENS

Three copper base alloys were purchased for property evaluation and selection of a nozzle material: Cu-Be Alloy 10, Cu-Be Alloy 50, and Cu-Zr.

The chemical composition of these alloys and the specified condition of these materials are presented in the following table.

Alloy	Typical Composition	Condition
Cu-Be Alloy 10	0.40-0.70% Be 2.35-2.70% Co Balance Cu	Annealed and heat treated approximately 3 hr at 900°F
Cu-Be Alloy 50	0.25-0.50% Be 1.40-1.70% Co 0.90-1.10% Ag Balance Cu	Annealed and heat treated approximately 3 hr at 900°F
Cu-Zr	0.13-0.15% Zr Balance oxygen-free copper	Annealed, cold forged to approximately 75% CW, and aged 1 to 2 hr at 750-800°F

These materials were purchased in billets with a nominal 3-in. diameter and 12 in. long. The billets were then sawed into pieces from which the specimens were machined. Figure 9 shows a typical tensile specimen used in this program. The specimens were cut from the billet so that the cross section was parallel to the billet cross section. The number of specimens obtained from the billet cross section ranged from 7 to 16 depending on the specimen size. The total number of specimens tested was 55; however, not all specimens tested are reported herein since some of the materials were not received in the condition required by the purchase specifications.

5.2 TEST PROCEDURE

The specimens were numbered according to their distance from the billet centerline. Tests at room temperature were then performed to determine if a property pattern existed in the billet cross section because of uneven cold working and heat treatment. Once it was established that no differences in data existed because of specimen location in the billet cross section beyond normal experimental data scatter, the elevated-temperature tests were performed irrespective of specimen location.

A total of 30 specimens were tested at room temperature and 25 specimens were tested at elevated temperatures. For the beryllium-copper, tests were made at room temperature and elevated temperatures at intervals of 100°F beginning at 200°F. Tests on Cu-Zr were performed at room temperature and elevated temperatures at 200°F intervals beginning at 200°F. For all tests, measurements were recorded for ultimate and 0.2-percent yield strengths, percent elongation, and percent reduction of area. The modulus of elasticity was measured at room temperature only.

Hardness tests were made across the billet to determine billet uniformity. Also random hardness tests were made on the specimens after tensile tests were completed. The chemical composition of each material was checked for proper alloying constituents.

5.3 TEST RESULTS

The results are analyzed and presented from tests on two Cu-Be billets and four Cu-Zr billets. Data from these tensile tests at room temperature are shown in Table VI. The strength and hardness levels of the Cu-Be alloys were considerably higher than those of Cu-Zr. However, the modulus of elasticity and percent elongation were about equal. Of the Cu-Be alloys, Alloy 10 had the higher strength resulting primarily from the higher Be percentage.

The four Cu-Zr billets in Table VI were received with different levels of hardness. The effectiveness of the cold-working procedure is indicated by the hardness of this alloy. Thus the data presented in Table VI for Cu-Zr were separated into four hardness levels. Two of the Cu-Zr alloys are above the normal Zr range of 0.13- to 0.15-percent Zr. However, as indicated in Ref. 11, the higher Zr content should not affect the properties of the alloy significantly.

The ultimate strength of Cu-Zr ranged from 44,800 to 56,400 psi depending upon the hardness level, and both the ultimate and yield strengths increased as the hardness increased. The Cu-Zr had a much higher percent reduction of area than the Cu-Be alloys, which indicates that Cu-Zr showed considerable "neck down" prior to specimen failure, whereas the Cu-Be was characterized by uniform yielding followed by fracture (see Fig. 10).

The tensile strength of Cu-Be Alloys 10 and 50 is presented in Fig. 11 at elevated temperatures. The ultimate strength for both materials decreased rapidly as the temperature increased to 500 and 600°F. However, the yield strength remained nearly constant with only a slight tendency to decrease with increasing test temperature.

Strength data at elevated temperatures to 1000°F are presented in Fig. 12 for the Cu-Zr materials. The highest cold-worked billets generally exhibited the highest strength levels throughout the temperature range; however, the advantage was less at the higher test temperatures. As shown in Fig. 12, the Cu-Zr maintained a high percentage of the room temperature strength at temperatures up to 800°F.

The other properties measured for the elevated-temperature tests were the percent elongation and percent reduction of area. The elongation data are presented in Fig. 13 for Cu-Be and Cu-Zr. The elongation for Cu-Be was approximately 20 percent but decreased sharply at 400°F (Fig. 13a). The Cu-Zr data ranged from 15- to 22-percent elongation for all temperatures up to 1000°F (Fig. 13b). The percent reduction of area for these same alloys is shown in Fig. 14. The average reduction of area for Cu-Zr is 70 percent, which increased to 77 percent at 1000°F. The Cu-Be alloys, however, which had an average reduction of area of 30 percent at temperatures up to 300°F, showed a sharp decrease at 400°F and above. The photograph of the Cu-Be and Cu-Zr specimens tested at 600°F (Fig. 15) illustrates the type of fracture characteristic of these materials. At temperatures above 500°F, the Cu-Be specimen generally fractured at points of high local stress, that is, at the base of the threads at the specimen end or at punch marks used for strain measurements. These fractures indicate the brittleness of this material at elevated temperature.

SECTION VI
COMPARISON OF AVAILABLE DATA WITH TEST RESULTS

The experimental test data were compared with the tabulated data presented in this report from other sources. The data in Table VI for Cu-Be Alloy 10 show experimental values of 109,600 and 80,900 psi for the ultimate and 0.2-percent yield strengths, respectively. These strengths, when compared with Alloy 10 (AT) in Table II, lie within the range of most of the strength values listed and at the upper end of the strength range for the billet of Ref. 6. The elevated-temperature properties are compared in Fig. 16. The experimental strength data for Alloy 10 are equal to or greater than the curves of Ref. 9, whereas the percent elongation data are about equal to the referenced data.

No direct comparisons could be made for the Alloy 50 since all referenced data are in the HT condition; however, higher strength values were expected for the referenced data as a result of the cold working.

The Cu-Zr experimental strength data at room temperature in Table VI, when compared with that in Table III, showed the referenced data in general to have strengths listed which are higher than the experimental data. However, the data for 40-percent cold-worked sheet and rod in Ref. 8 compare with strength data obtained in some of the experimental tests on cold-worked billets. Elevated-temperature tests on two Cu-Zr billets are compared with cold-worked 0.25-in.-diam specimens of Ref. 10 in Fig. 17. The experimental data had strength levels approximately two-thirds of the data level shown from Ref. 10 at temperatures up to 600°F. From 600 to 1000°F the decrease in strength of the referenced data was much greater than the experimental data. The exact percent of cold working for the experimental test data was unknown; however, considerable size reduction in the billet by cold forging was accomplished as evidenced by the hardness levels shown for these billets. While the area reduction may have been as much as 75 percent in the billets tested, the effective cold working was reduced by the inability to obtain uniform hardening in large size billets.

The experimental test data indicated that the Cu-Be alloys can be obtained in large billets with strength as high as would be expected from published data, since the strength above the annealed level is derived primarily from age hardening. Conversely, the strength of Cu-Zr billet materials cannot be expected to reach values listed for small highly cold-worked specimen rods and wires, since the primary increase in strength above the annealed strength level for Cu-Zr alloy is accomplished by mechanical working. These results were expected since materials in large size pieces are easier to age uniformly than to work harden effectively.

SECTION VII
CONCLUDING REMARKS

The selection of an alloy for high heat flux requirements depends upon the particular application intended. The Cu-Be Alloy 25 had the highest strength of the alloys reported but the lowest thermal conductivity, whereas ETP copper and oxygen-free copper both have much lower strength but with thermal conductivity approaching that of pure copper. The other copper alloys can be grouped into categories which have strengths less than Alloy 25 and conductivities less than the unalloyed coppers. The product of strength and thermal conductivity is about equal for all of these copper alloys and therefore has equal potential for high heat flux applications. Other factors then dictate the choice of alloy selected. For example, oxygen-free copper and ETP copper (Fig. 8) showed sharp decreases in strength above 300°F. The Cu-Be alloys showed similar results above 500°F (Figs. 2 and 4). The Cu-Zr and Cu-Cr both maintained a high percentage of their room temperature strength up to 800°F. However, at elevated temperatures Cu-Cr and Cu-Be Alloys 10 and 50 exhibited hot brittleness (Figs. 4, 7, and 13a). The Cu-Zr has the best elevated-temperature characteristics in that it maintains most of its room temperature strength to 1000°F without becoming brittle. However, it is normally a much softer and lower strength alloy than the Cu-Be alloys. These factors all contribute to the proper selection of a material for high heat flux applications.

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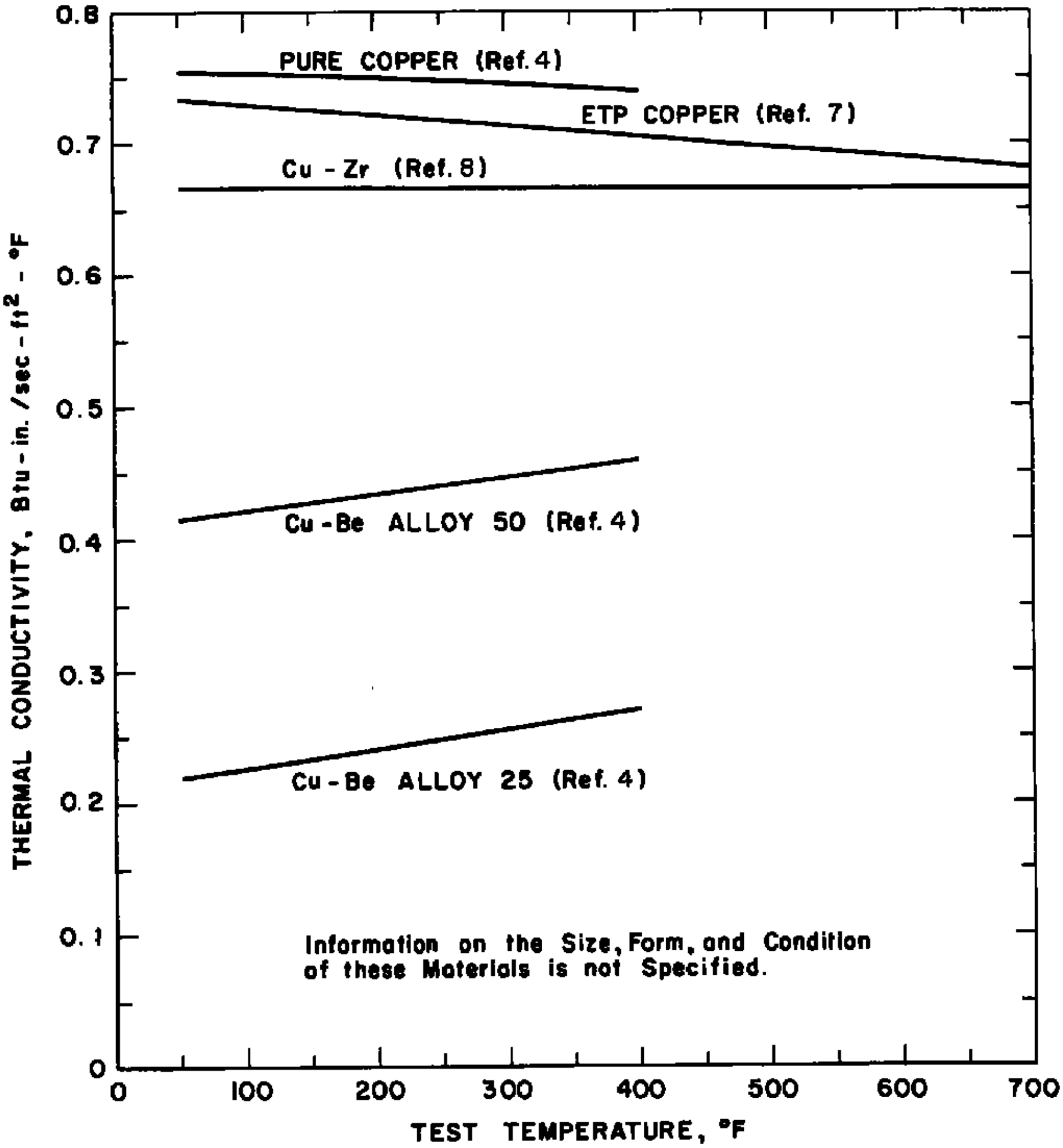


Fig. 1 Typical Values of Thermal Conductivity of Copper Base Alloys at Elevated Temperatures

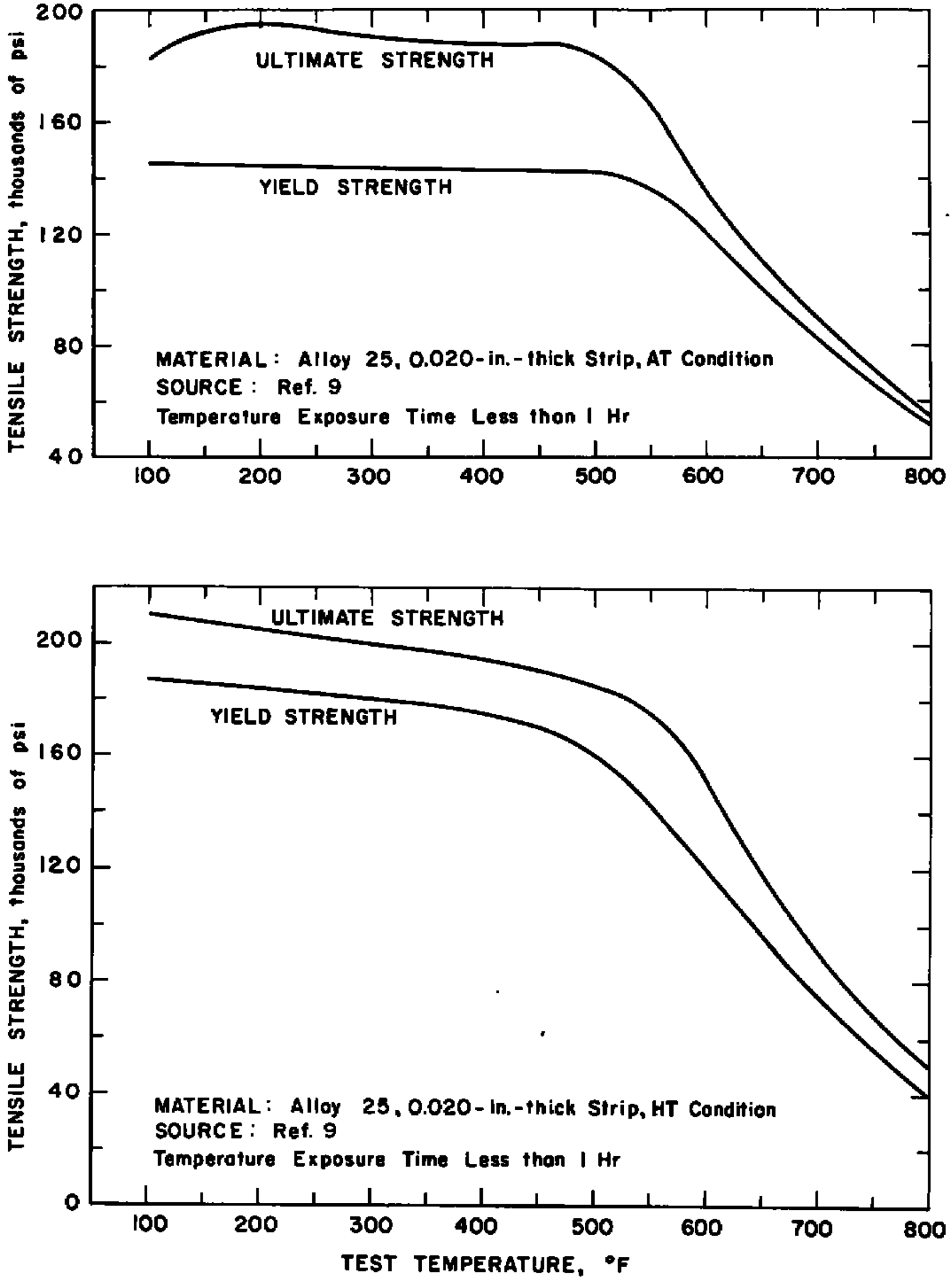


Fig. 2 Elevated-Temperature Strength of Cu-Be Alloy 25

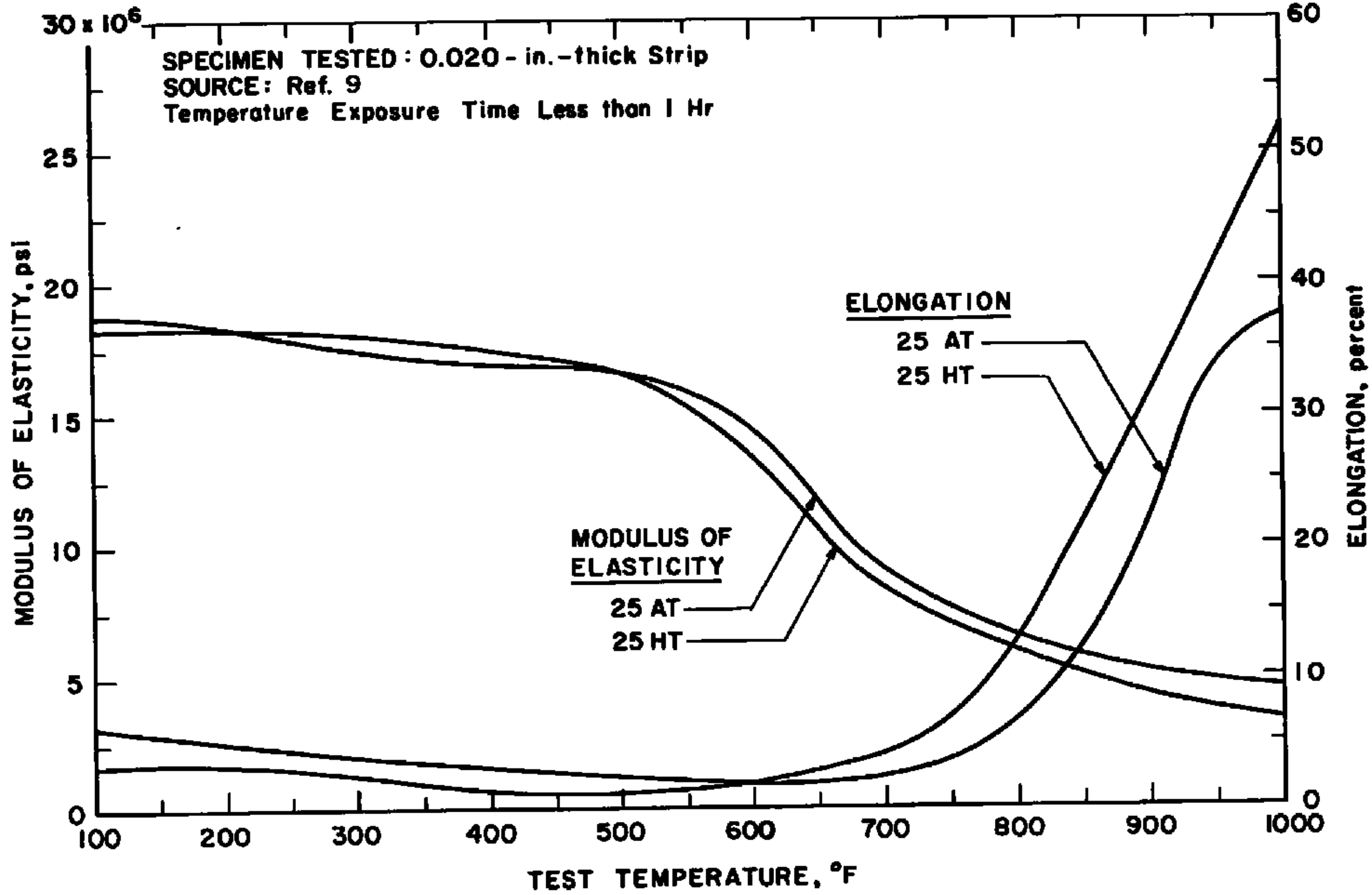


Fig. 3 Elongation and Modulus of Elasticity of Cu-Be Alloy 25 at Elevated Temperatures

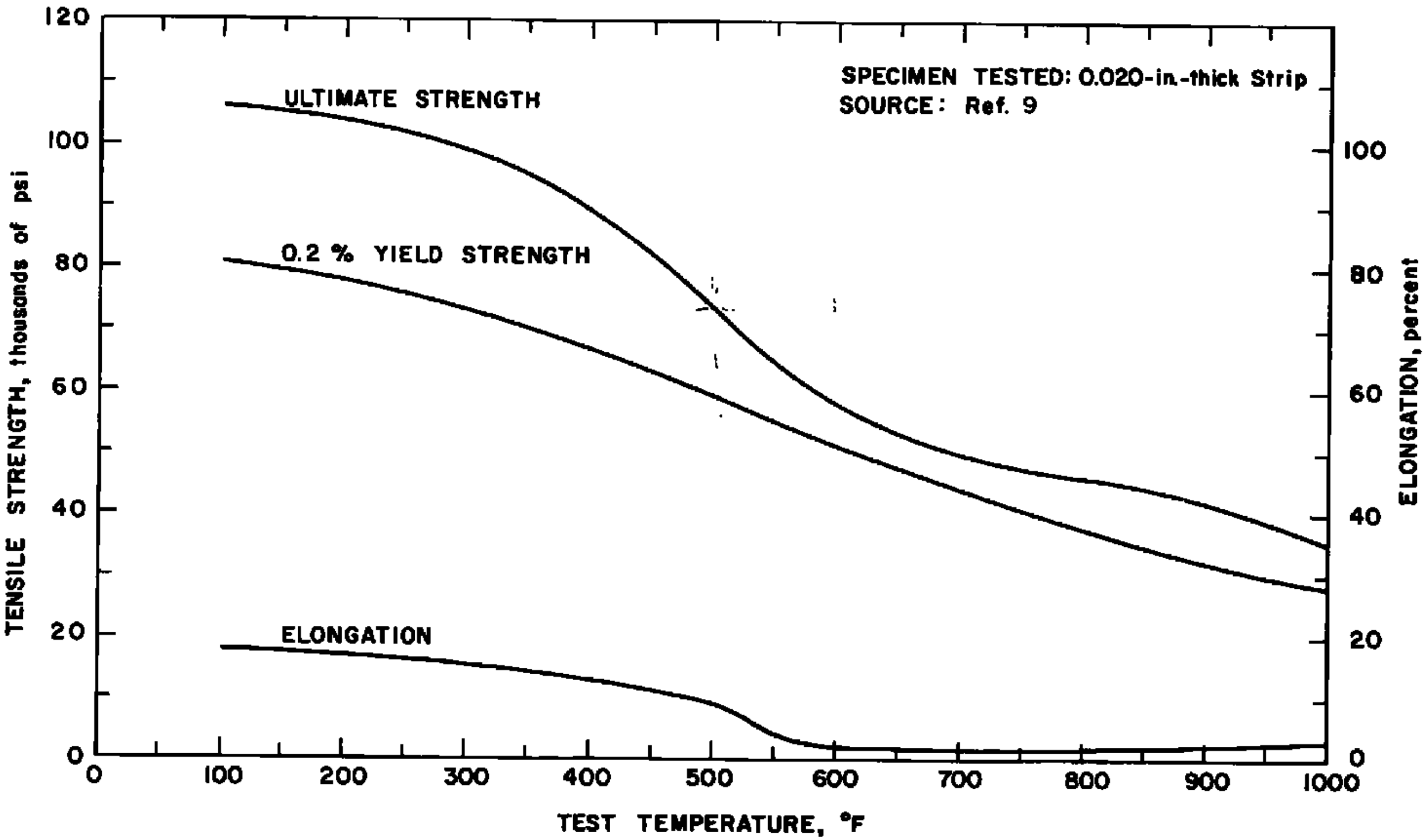


Fig. 4 Elevated-Temperature Properties of Cu-Be Alloy 10 (AT Condition)

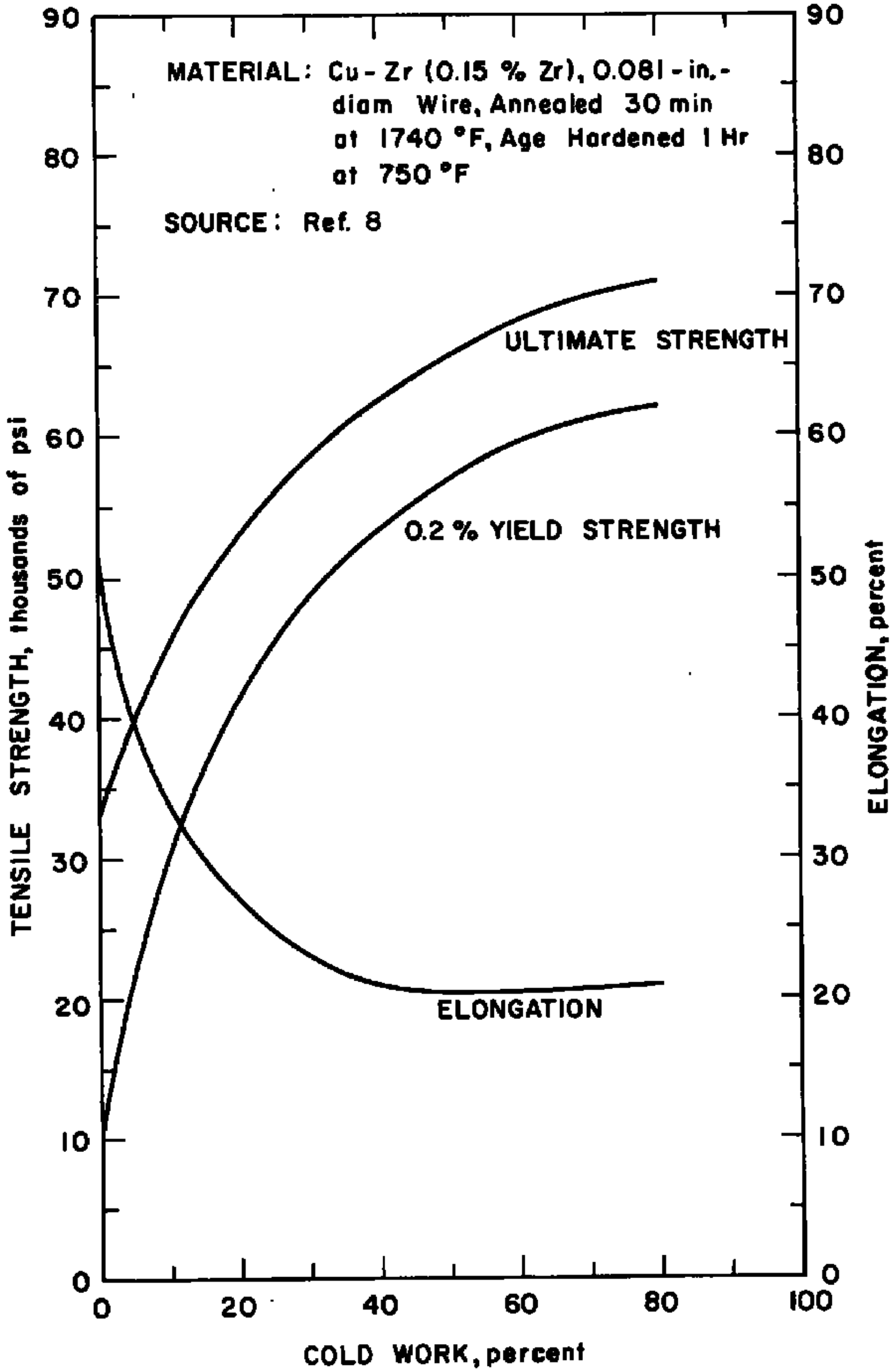


Fig. 5 Effect of Cold Work on the Mechanical Properties of Cu-Zr at Room Temperature

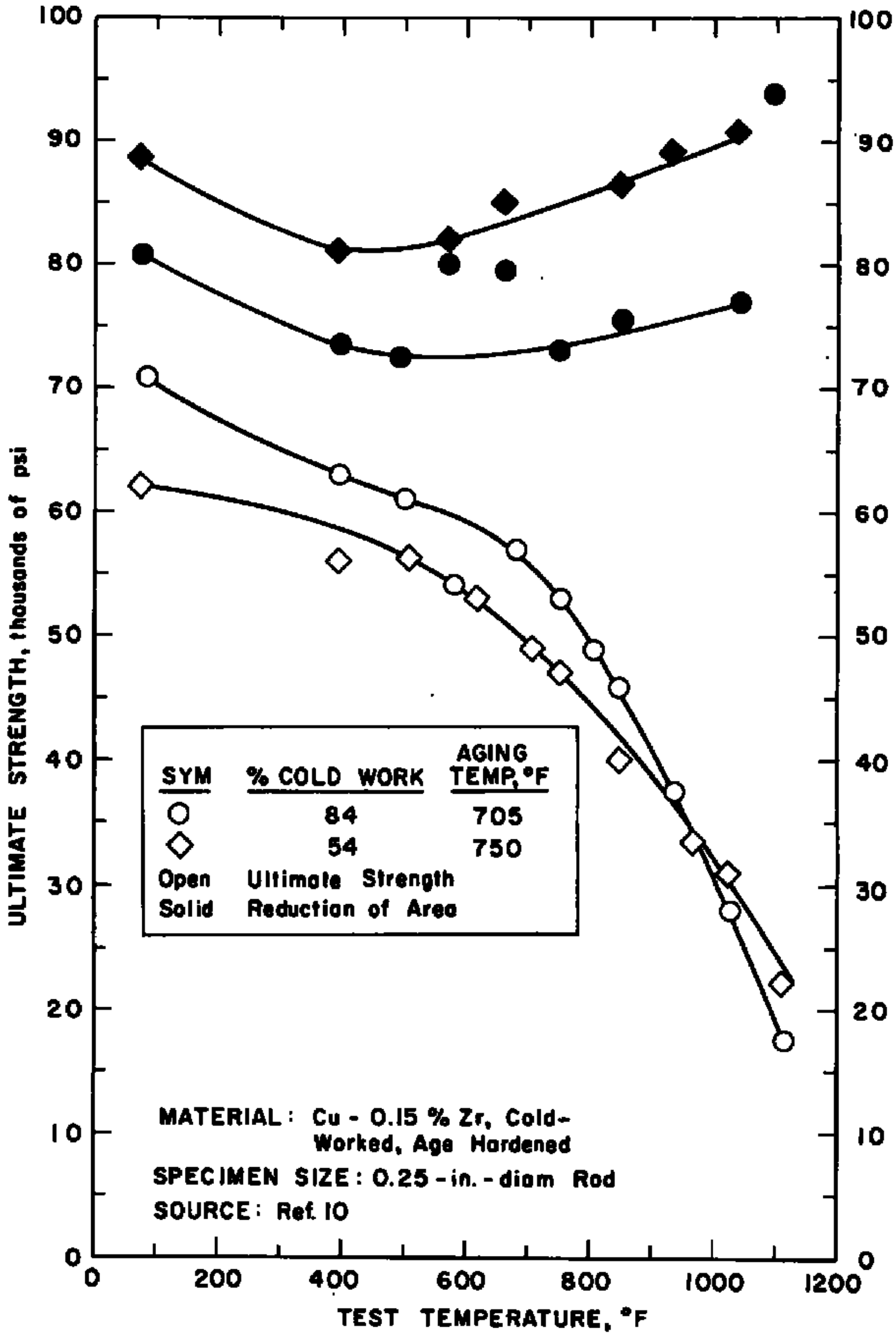


Fig. 6 Elevated-Temperature Properties of Cu-Zr Alloy

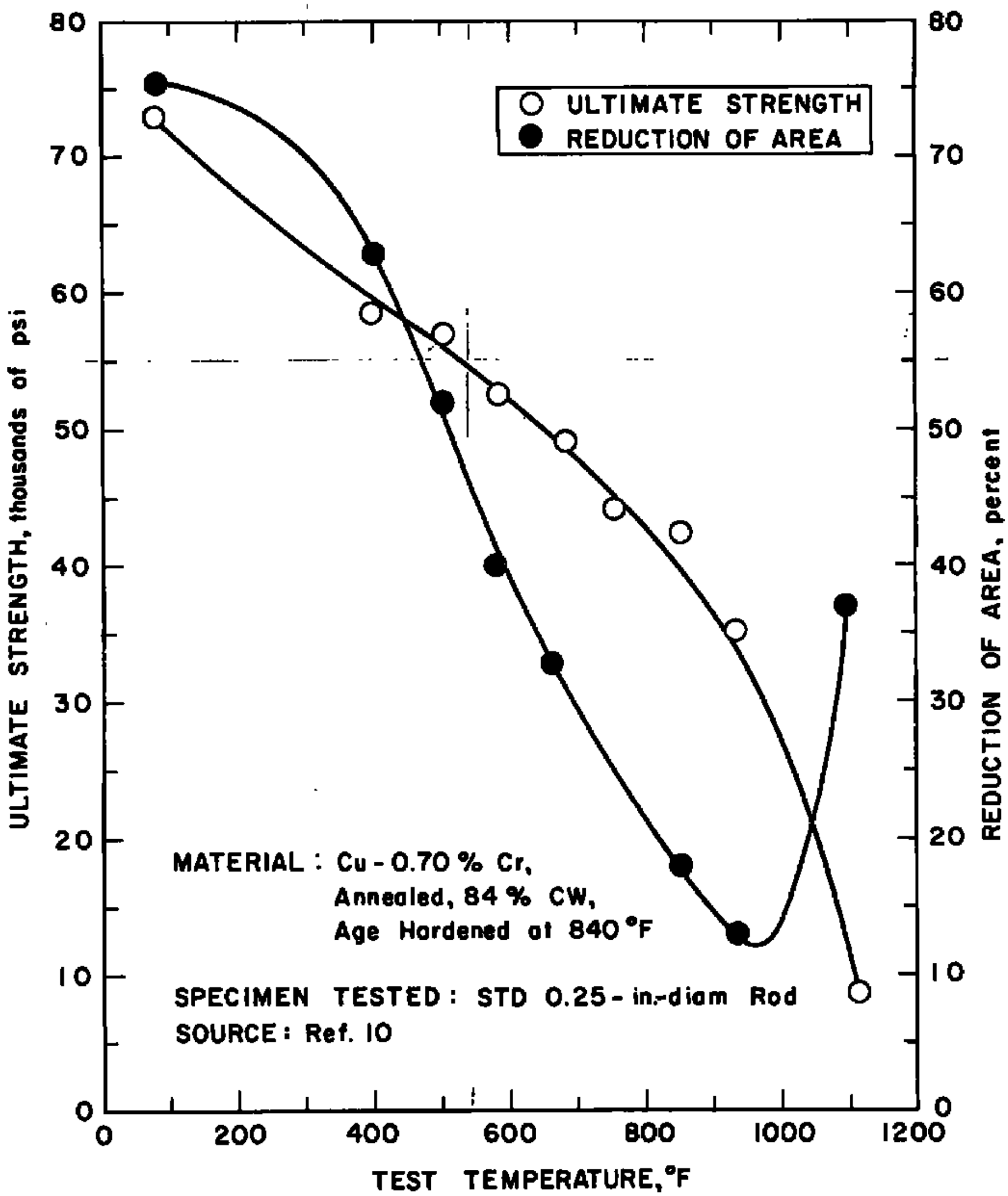


Fig. 7 Elevated-Temperature Properties of Cu-Cr with 84-percent Cold Work

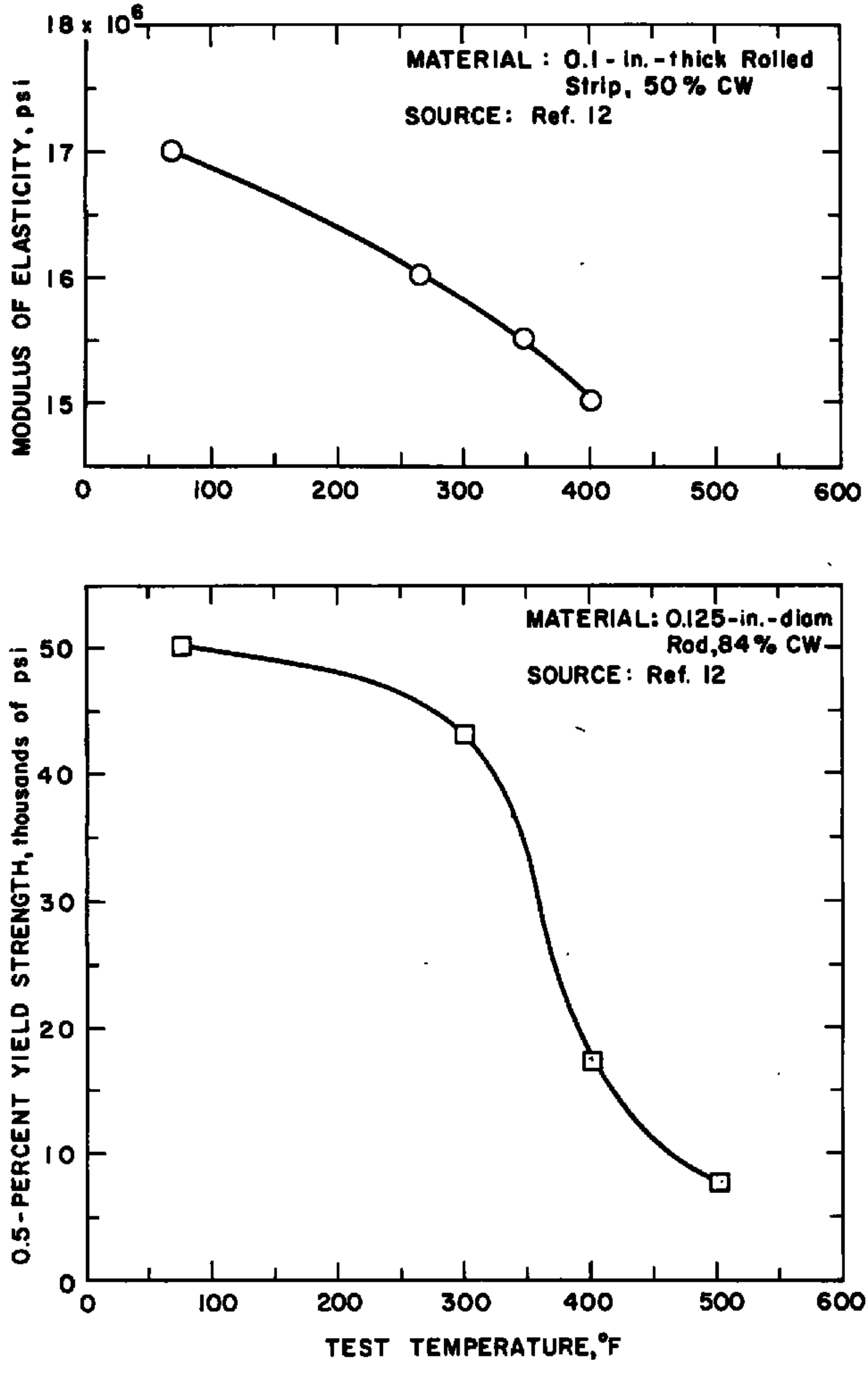
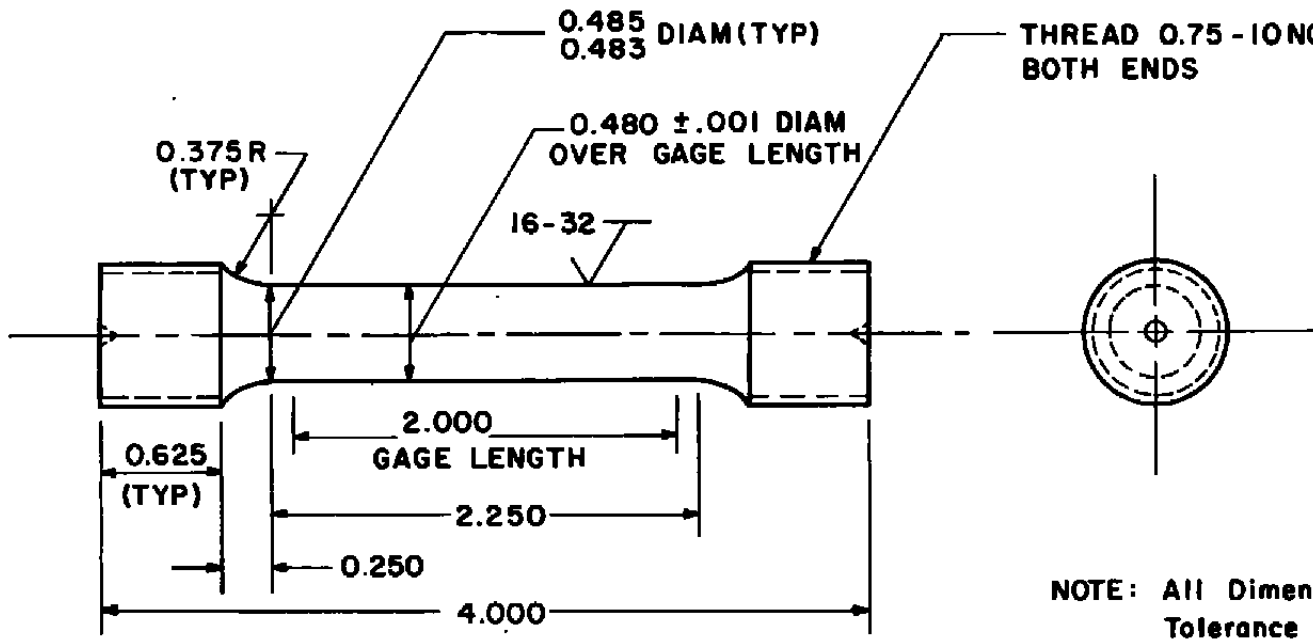


Fig. 8 Elevated-Temperature Properties of Electrolytic Tough Pitch Copper



NOTE: All Dimensions Have a Tolerance of ± 0.015 Unless Otherwise Noted

SCALE: Full Size

Fig. 9 Typical Tensile Test Specimen

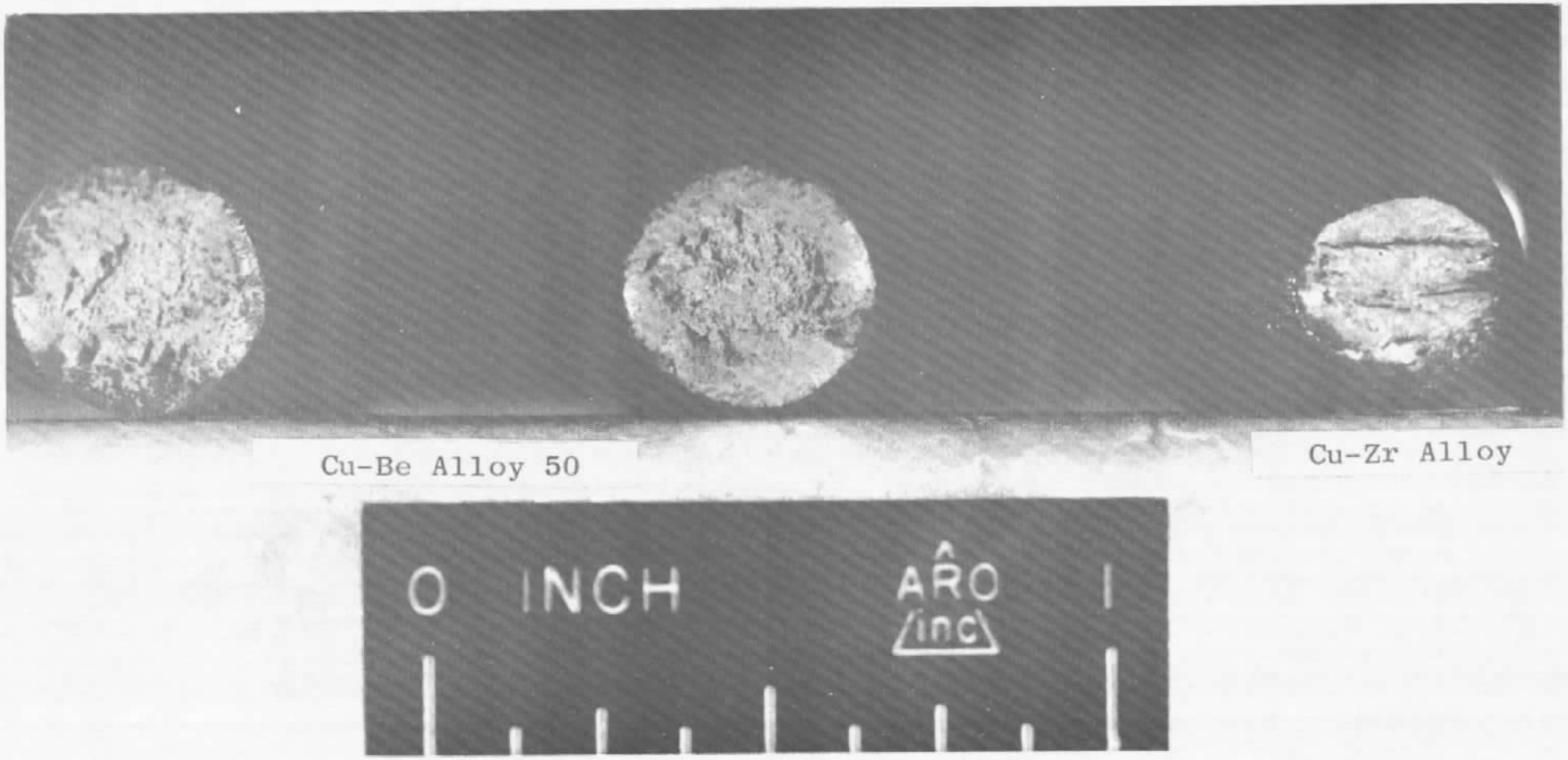


Fig. 10 Room Temperature Fracture of Cu-Be and Cu-Zr Test Specimens

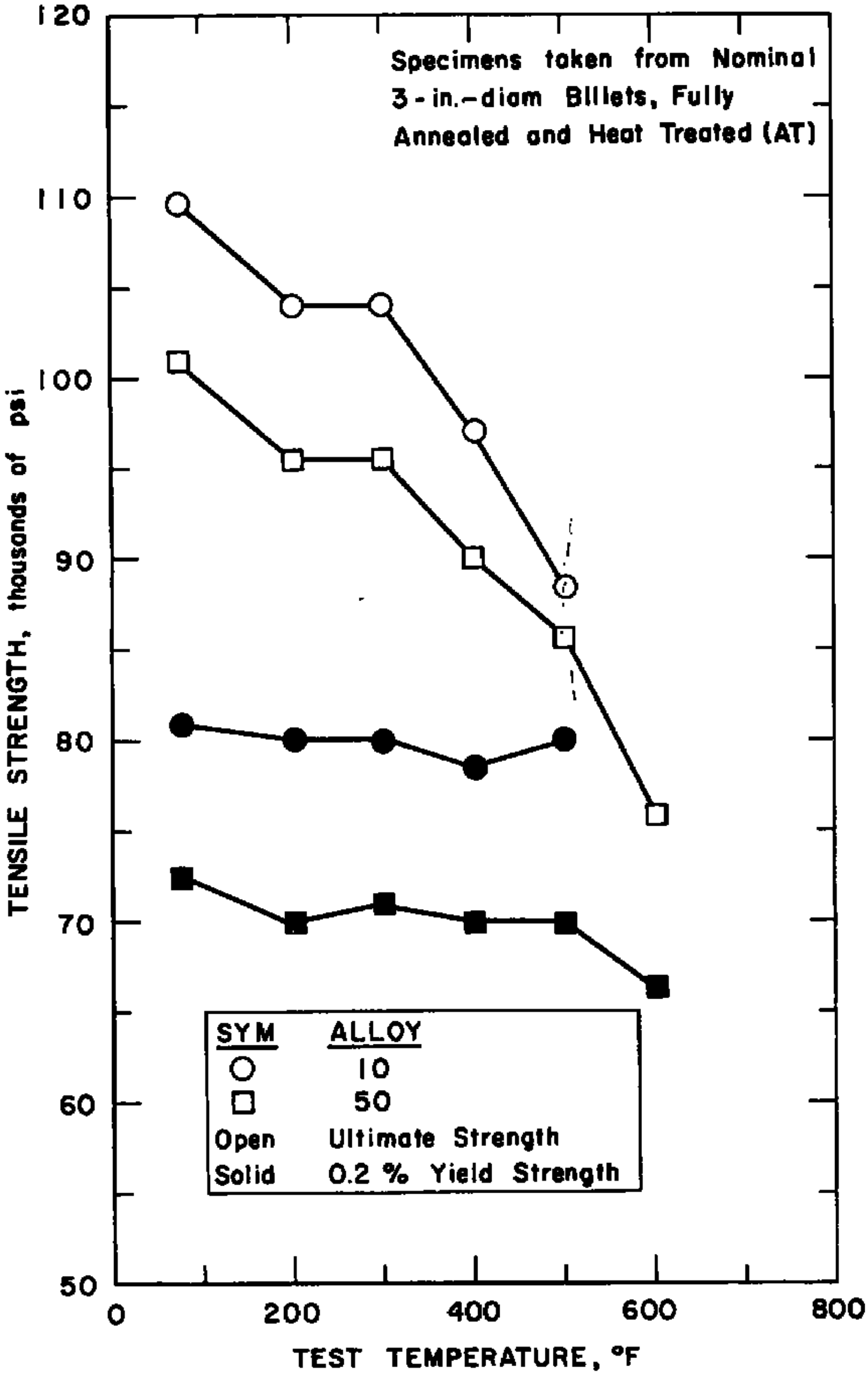
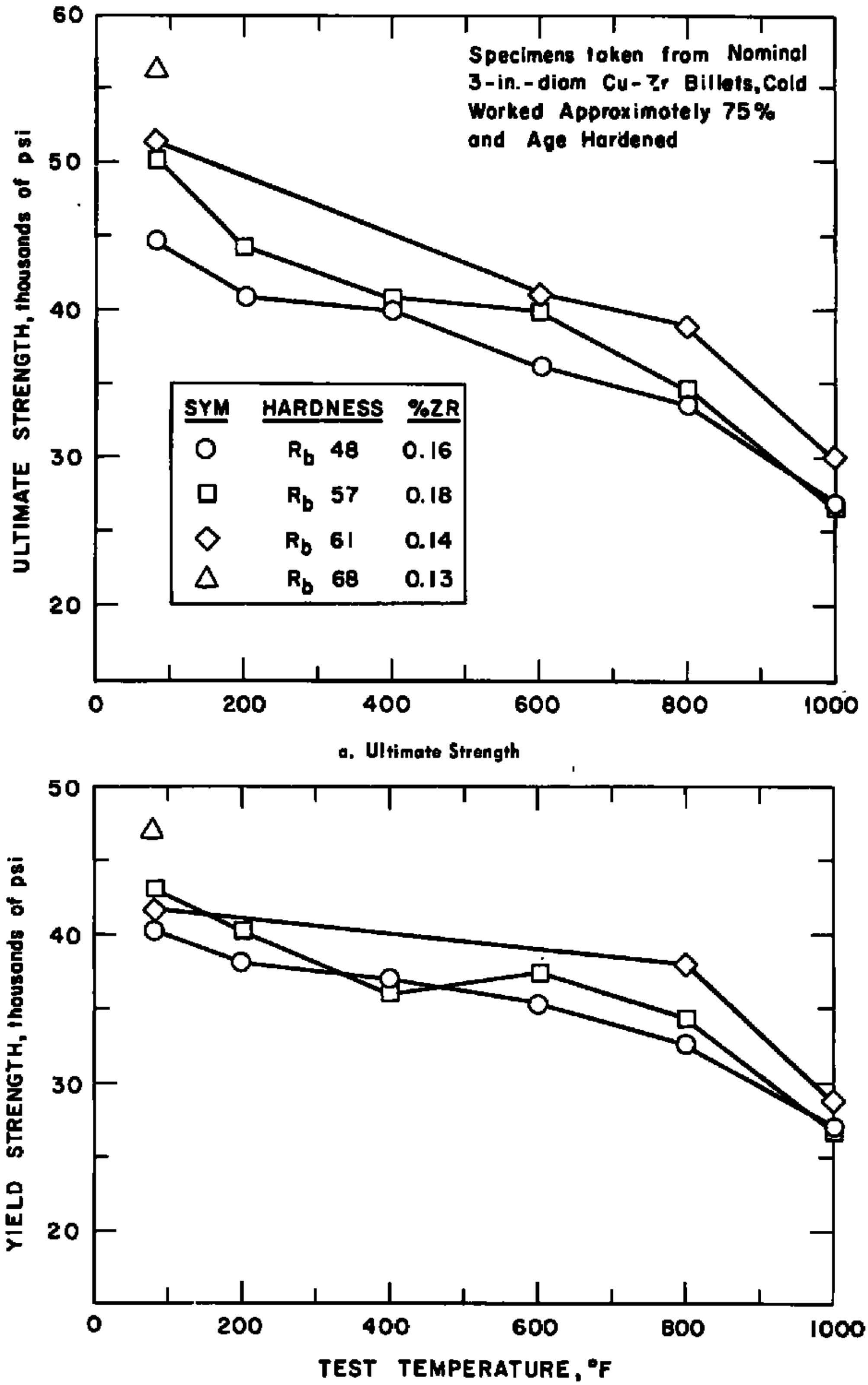
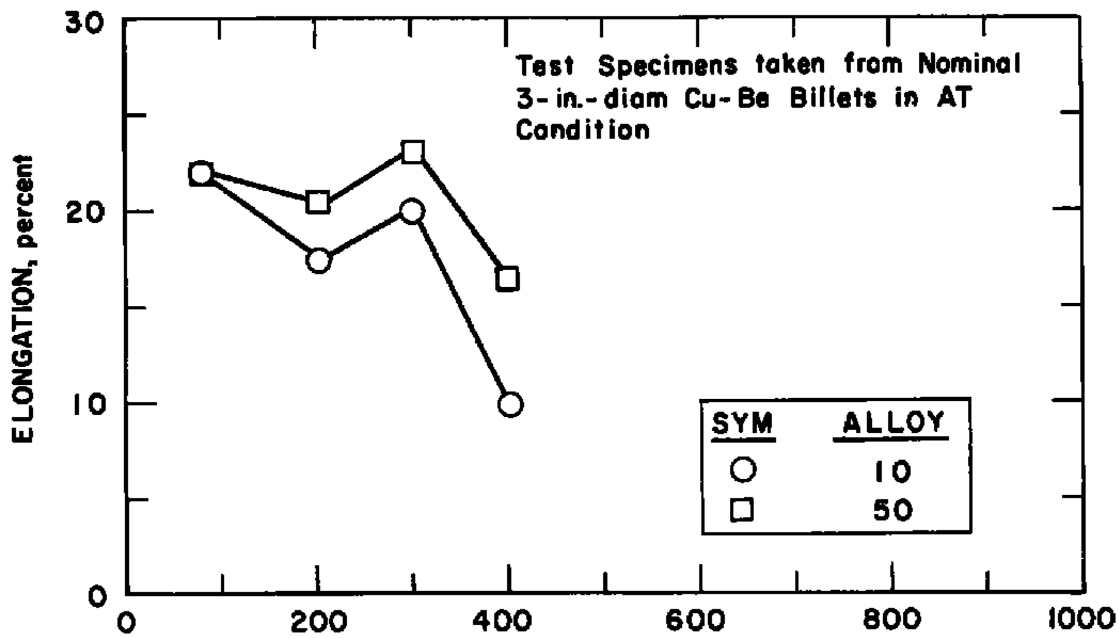


Fig. 11 Experimental Strength Data of Two Cu-Be Alloys at Elevated Temperatures

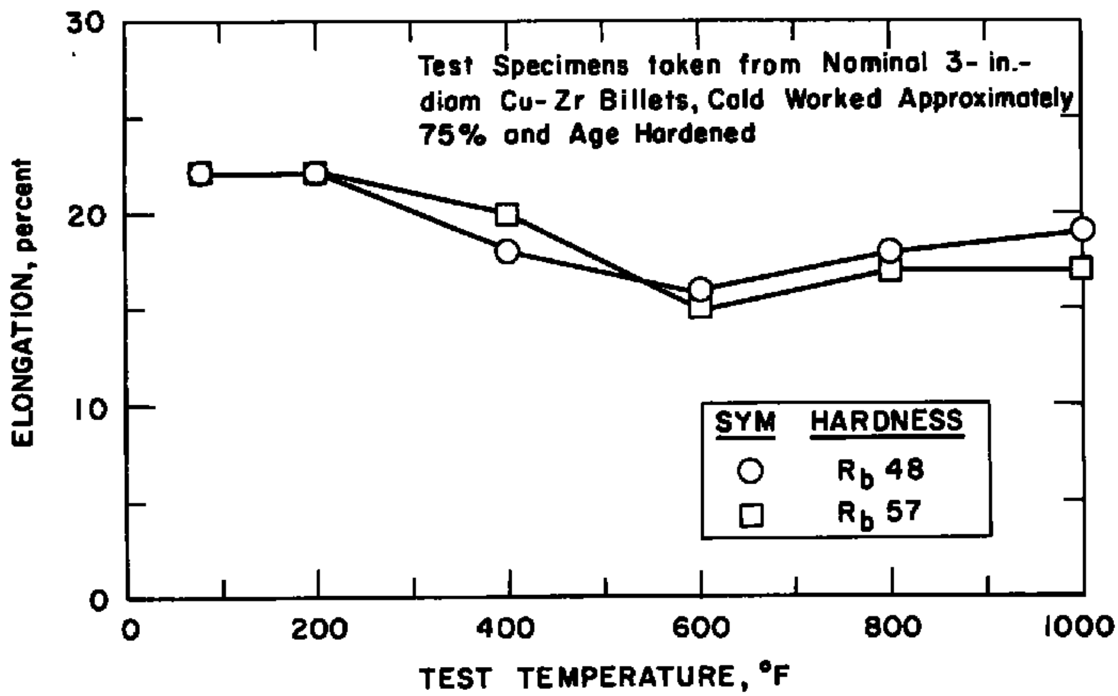


b. 0.2-percent Yield Strength

Fig. 12 Experimental Strength Data of Cu-Zr Alloy at Elevated Temperatures



a. Cu-Be Alloys



b. Cu-Zr Alloys

Fig. 13 Elongation Test Data of Copper Alloys at Elevated Temperatures

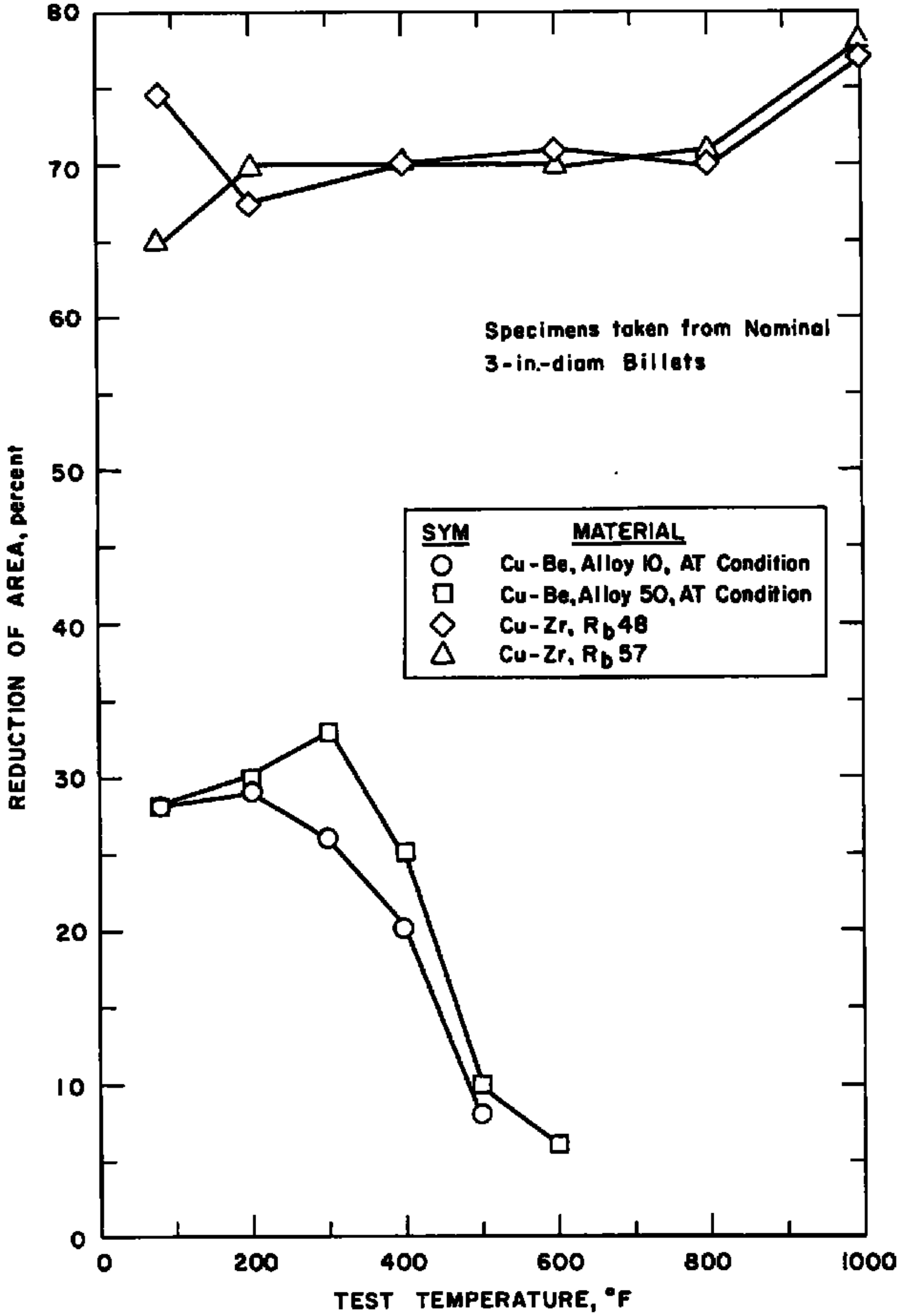


Fig. 14 Reduction of Area Test Data of Copper Alloys at Elevated Temperatures

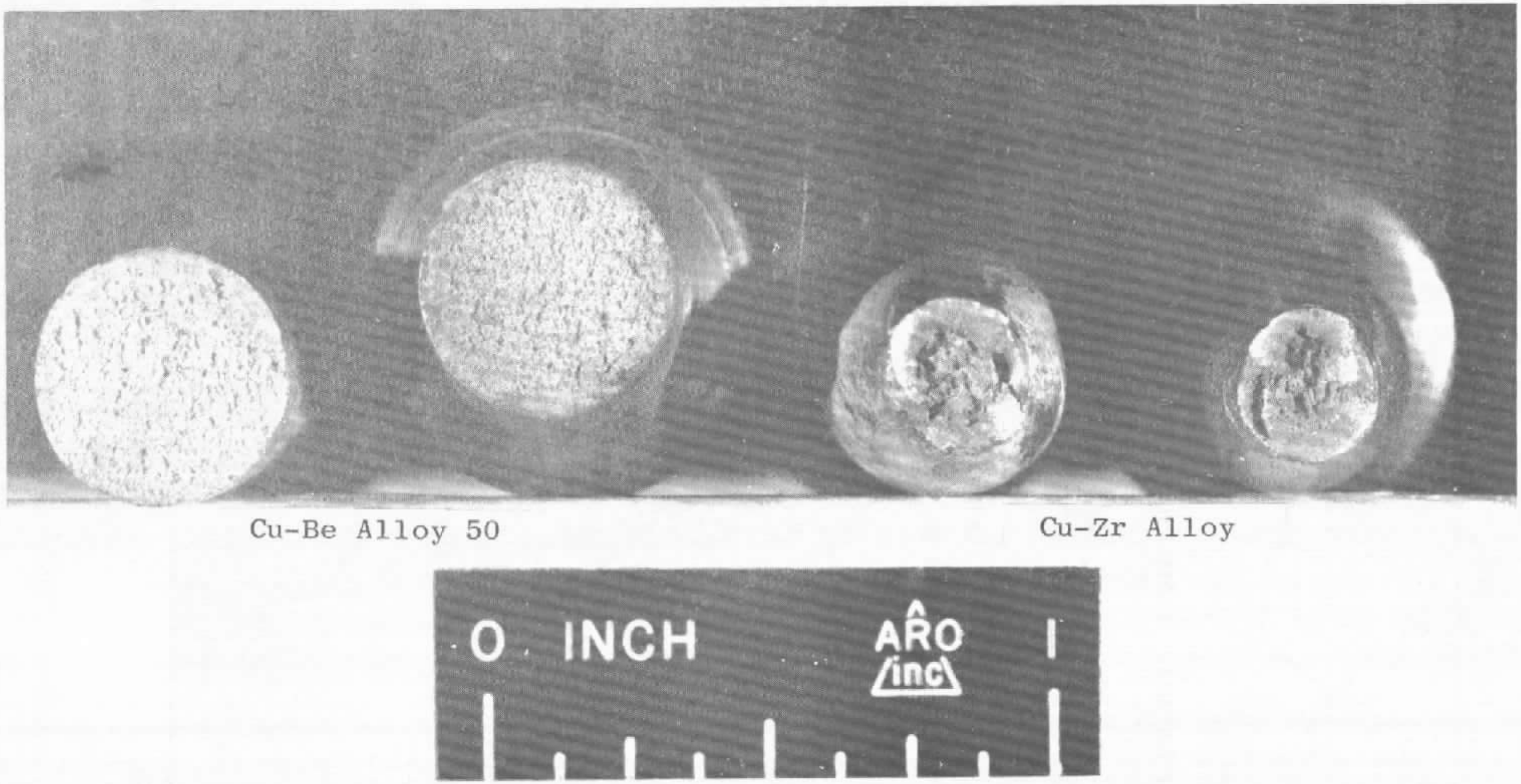


Fig. 15 Fracture of Cu-Be and Cu-Zr Test Specimens at 600 °F

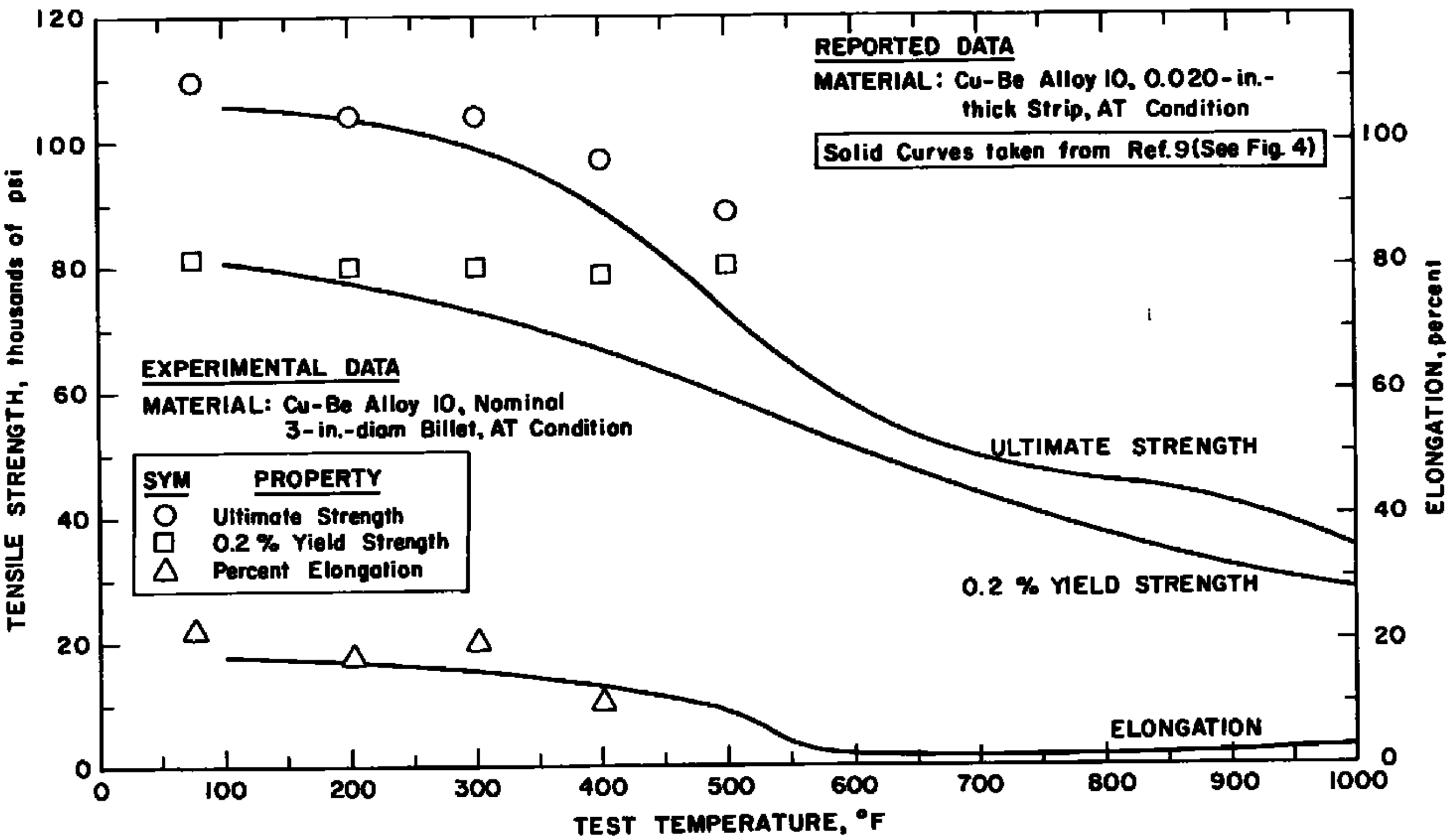


Fig. 16 Comparison of Experimental Data with Reported Properties of Cu-Be Alloy 10 at Elevated Temperatures

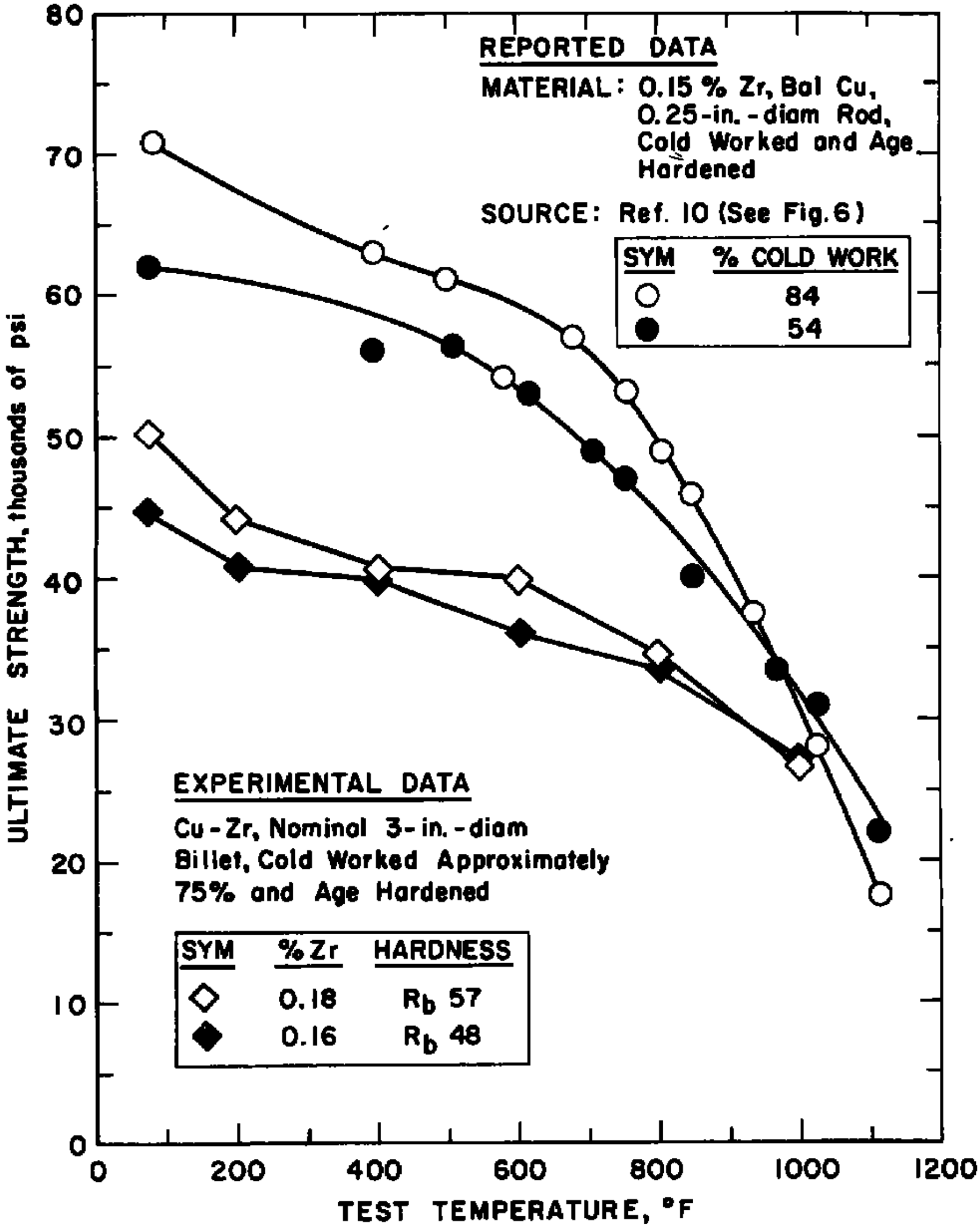


Fig. 17 Comparison of Experimental Data with Reported Properties of Cu-Zr Alloy at Elevated Temperatures

TABLE I
ROOM TEMPERATURE PROPERTIES OF HIGH STRENGTH Cu-Be ALLOYS

Alloy	Ultimate Strength x 10^{-3}, psi	0.2-percent Yield Strength x 10^{-3}, psi	E x 10^{-6}, psi	Elong, percent	R of A, percent	α x 10^{6}, 1/°F	k, Btu-in./sec-ft^2-°F	ν	Ref.
25 Strip (AT)	165-180	-	-	5-8	-	-	-	-	2
25 Strip (HT)	190-205	-	-	1-2	-	-	-	-	
25 Rod (AT)	165-180	-	-	3-10	-	-	-	-	
25 Rod (HT)	185-215	-	-	2-5	-	-	-	-	
25 (AT)	165-180	130-150	19	-	-	9.3	-	-	
25 (HT)	185-210	160-185	-	-	-	-	-	-	
25	-	-	-	-	-	-	0.21-0.25	0.30	
165 Strip (AT)	150-165	-	-	5-8	-	-	-	-	2
165 Strip (HT)	180-195	-	-	1-2	-	-	-	-	
165 (AT)	150-175	120-145	18.5	-	-	9.3	-	-	
165 (HT)	170-195	150-175	-	-	-	-	-	-	
165	-	-	-	-	-	-	0.21-0.25	-	
25 (AT)	165-180	130-150	19	3-12	5-15	9.2	0.24	-	3
25 (HT)	180-210	160-175	19	2-8	3-10	9.3	0.22	-	
25 (HT)	190-210	180-205	-	1-4	-	-	-	-	4
25 Strip (AT)	165-195	140-170	19	5-10	-	9.3	0.21-0.25	0.35	5
25 Strip (HT)	190-215	165-195	19	1-4	-	-	-	-	
25 Strip (AT)	165-190	140-175	18.5	4-10	-	-	0.22	-	6
25 Strip (HT)	190-215	165-205	-	1-4	-	-	-	-	
25 Bar and Plate (AT)	165-190	145-175	-	4-10	-	-	-	-	
25 Billet (AT)	150-175	120-150	-	1-3	-	-	-	-	
165 Strip (AT)	150-180	120-160	18	4-10	-	-	0.22	-	6
165 Strip (HT)	180-200	140-180	-	1-4	-	-	-	-	
165 Bar and Plate (AT)	150-180	125-155	-	4-10	-	-	-	-	
165 Billet (AT)	135-170	100-135	-	1-4	-	-	-	-	

TABLE II
ROOM TEMPERATURE PROPERTIES OF HIGH CONDUCTIVITY Cu-Be ALLOYS

Alloy	Ultimate Strength x 10^{-3}, psi	0.2-percent Yield Strength x 10^{-3}, psi	E x 10^{-6}, psi	Elong, percent	R of A, percent	$\alpha \times 10^{6}$, 1/°F	k, $\frac{\text{Btu-in.}}{\text{sec-ft}^2\text{-°F}}$	Ref.
10 Strip (AT)	100-110	-	-	8-12	-	-	-	2
10 Strip (HT)	105-130	-	-	5-10	-	-	-	
10 Rod and Bar (AT)	100-120	-	-	10-20	-	-	-	
10 Rod and Bar (HT)	110-130	-	-	8-15	-	-	-	
50 Rod and Bar (HT)	110-130	-	-	8-15	-	-	-	
10 (AT)	100-120	70-90	18	-	-	9.8	0.40-0.50	
10 (HT)	110-140	100-120	-	-	-	-	-	
50 (AT)	-	-	18	-	-	9.8	0.42-0.47	
50 (HT)	110-140	100-120	-	-	-	-	-	
10 (AT)	110-120	75-85	18	10-15	15-35	9.9	0.44-0.50	3
10 (HT)	120-140	80-90	18	8-12	10-30	9.8	0.39-0.44	
10 (HT)	110-130	100-120	-	5-13	-	-	-	4
10 Strip (AT)	100-110	80-100	-	8-12	-	-	0.44	6
10 Strip (HT)	110-125	100-120	-	5-8	-	-	-	
10 Bar and Plate (AT)	100-120	80-100	-	10-25	-	-	-	
10 Bar and Plate (HT)	110-130	100-120	-	8-20	-	-	-	
10 Billet (AT)	90-110	70-80	-	3-15	-	-	-	

TABLE III
ROOM TEMPERATURE PROPERTIES OF AGE HARDENED Cu-Zr ALLOY

Alloy Form	Ultimate Strength, psi	0.2-percent Yield Strength, psi	$E \times 10^{-6}$, psi	Elong, percent	R of A, percent	$\alpha \times 10^{6}$, 1/°F	k, $\frac{\text{Btu-in.}}{\text{sec-ft}^2\text{-°F}}$	Ref.
Rod 40% CW	50,000	44,000	-	20	-	-	-	8
Rod 80% CW	62,000	55,000	-	12	-	-	-	
Sheet, Hard	54,000	45,000	-	15	-	-	-	
Wire 40% CW	62,000	54,000	-	21	-	-	-	
Wire 80% CW	71,000	62,000	-	21	-	-	-	
- 83% CW	-	-	-	-	-	-	0.66	
Rod (0.25-in. diam) 54% CW	62,000	-	-	-	88	-	-	10
Rod (0.25-in. diam) 84% CW	71,000	-	-	-	81	-	-	
- 84% CW	-	-	-	-	-	9.04	-	
- 54% CW	-	-	19.3	-	-	-	-	11
Wire 90% CW	70,000	61,000	-	10	-	-	-	
Cold-Rolled	53,000	50,000	-	10	54	-	-	12
Rod (1-in. diam) (HT)	60,000	50,000	-	12	-	9.8	0.71	13

TABLE IV
ROOM TEMPERATURE PROPERTIES OF ELECTROLYTIC TOUGH PITCH COPPER

Alloy Form	Ultimate Strength, psi	0.2-percent Yield Strength, psi	$E \times 10^{-6}$, psi	Elong, percent	R of A, percent	$\alpha \times 10^{6}$, 1/°F	k, $\frac{\text{Btu-in.}}{\text{sec-ft}^2\text{-°F}}$	Ref.
Rod(1/8-in. diam), 84% CW	55,400	49,500	18.0	11.0	-	-	-	12
Strip(0.1-in. thick), 50% CW	52,500	46,000*	17.0	14.0	-	-	-	↓
Rod(1-in. diam), Hard	48,000	40,000**	-	15.0	-	9.8†	0.75	13
Wire(0.080-in. diam), Hard	66,000	-	-	1.5	-	9.8	0.75	↓
Rod	-	-	-	-	-	9.5	0.73	7
Wire (0.081-in. diam) 84.4% CW	65,200	65,000	-	1.5	54	-	-	14
Wire (0.081-in. diam) 37.1% CW	57,000	55,000	-	2.0	64	-	-	
Rod (0.257-in. square) 20.5% CW	45,700	43,400	-	3.5	61.5	-	-	
Rod (0.257-in. square) 8.5% CW	35,300	30,500	-	27.0	63	-	-	↓

*0.1-percent offset

**0.5-percent offset

† α values are average coefficients in the temperature range from ambient to 600°F.

TABLE V
ROOM TEMPERATURE PROPERTIES OF OXYGEN-FREE COPPER

Alloy Form		Ultimate Strength, psi	0.2-percent Yield Strength, psi	Elong, percent	R of A, percent	$\alpha \times 10^6$, 1/°F	k, $\frac{\text{Btu-in.}}{\text{sec-ft}^2\text{-°F}}$	Ref.
Rod (1-in. diam), Hard		48,000	40,000*	15	-	9.8	0.75	13
Tube (1-in. diam), Hard		45,000	40,000*	-	-	-	-	
Wire (0.081-in. diam)	84.4% CW	66,300	66,000	1.5	91	-	-	14
	37.1% CW	57,500	57,000	2.0	91	-	-	
Rod (0.257-in. square)	20.5% CW	45,000	44,100	4.5	85.5	-	-	
	8.5% CW	34,400	29,400	30	88	-	-	

TABLE VI
EXPERIMENTAL ROOM TEMPERATURE DATA FOR VARIOUS 3-IN.-DIAM COPPER ALLOY BILLET MATERIALS

Alloy Composition	No. of Specimens Tested	Hardness, R_b	Ultimate Strength, psi	0.2-percent Yield Strength, psi	E x 10^{-6}, psi	Elong, percent	R of A, percent
Cu-Be Alloy 10 (AT)							
0.68% Be, 2.25% Co, Bal. Cu	3	94	109,600	80,900	20	22	28
Cu-Be Alloy 50 (AT)							
0.40% Be, 1.50% Co, 1.00% Ag, Bal. Cu	3	93	100,900	72,500	19	22	28
Cu-Zr							
0.16% Zr, Bal. Cu	2	48	44,800	40,200	17.7	22	74.6
0.18% Zr, Bal. Cu	3	57	50,200	43,000	17.7	22	65
0.14% Zr, Bal. Cu	5	61	51,400	41,700	19.2	25.3	73
0.13% Zr, Bal. Cu	8	68	56,400	47,000	18.9	24.9	73.3

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13 ABSTRACT

An investigation was made to determine the properties of copper base alloys at room and elevated temperatures for high heat flux applications. Literature surveys were conducted to study the properties of copper-beryllium, copper-zirconium, and other commercial grades of copper and copper alloys. These properties were compared with experimental data for copper-zirconium and two alloys of copper-beryllium at temperatures up to 1000°F. The test data indicated that the copper-beryllium alloys can be obtained in large sizes with strength levels comparable to survey property levels, whereas for copper-zirconium it was more difficult to reach tabulated strengths because the effectiveness of cold working was reduced for large size billets. The final selection of an alloy depends upon the requirements of a specific application.

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