NATIONAL BUREAU OF STANDARDS REPORT

5340

Progress Report

on

PHYSICAL PROPERTIES OF
CHROMIUM-COBALT DENTAL ALLOYS

by

Duane F. Taylor
Walter A. Leibfritz
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

PHYSICAL PROPERTIES OF
CHROMIUM-COBALT DENTAL ALLOYS

Abstract

The chemical composition and some physical properties of a group of commercial chromium-cobalt dental alloys have been investigated. Spectrographic and wet chemical analyses were made and liquidus temperature, hardness and various tensile properties were determined.

As others have reported, it was found to be desirable to use threaded enlarged-end specimens rather than straight rods for tensile tests. In addition to the expected variation in properties between alloys, considerable difference was found between lots of a single alloy cast by various laboratories. Use of a controlled atmosphere furnace was required for liquidus temperature determinations because the alloys react readily with oxygen. A vacuum furnace, suitable for use with very small samples, was developed and employed for this purpose.

1. INTRODUCTION

The first patent on the chromium-cobalt alloys was obtained by Elwood Haynes in 1907 [1]. However, it was not until 1937 that R. W. Erdle and C. H. Prange of the Austenal Laboratories perfected the materials and techniques for the

use of these alloys in dental applications [2]. Since their introduction into dentistry, the chromium-cobalt alloys have made steady gains in popularity until, at present, the great majority of all partial dentures are made of material of this type. This increased use can be attributed to their low density, low material cost, and high modulus of elasticity in comparison to gold alloys.

This paper gives the results of tests of the physical properties of six commercial alloys, obtained by use of specimens comparable in size to dental appliances. The properties determined were: tensile strength, modulus of elasticity, yield strength, percent elongation, superficial hardness, and liquidus temperature.

Several studies of these alloys have been made in relation to their dental application. In addition to the work of Erdle and Prange; Paffenbarger, Caul, and Dickson at the National Bureau of Standards[3] and Bush, Ingersoll, and Peyton at the University of Michigan [4] have made special contributions to the field. The manufacturers of commercial dental alloys have compiled significant data on their own products. It was felt, however, that additional information was required to define the properties to be expected of currently available products and to serve as the basis for a proposed specification for these materials. It was also desired to investigate the reported superiority of the threaded

enlarged-end specimen to the straight rod specimen for tensile tests of these materials and to compare the properties of specimens of these materials as cast by various laboratories under what they ostensibly believe to be the best conditions.

The six alloys tested include five American products and one popular European alloy. The American materials were selected to give a representative sample of the products on the market at the present time. The group included new products as well as established products which had been tested previously. The European alloy selected has been used with some success by the armed forces in Europe and is believed to be typical of the better products available there.

These products can be divided into two classes on the basis of their composition. The first, containing approximately 60% cobalt and the second, less than 45% cobalt. Table 1 shows the composition of the alloys tested. Of the two alloys with less than 45% cobalt, the one with the high iron content, (Alloy C), has been withdrawn from the market since the start of this project.

2. EXPERIMENTAL PROCEDURE

In the course of this study, two types of specimens were employed. In the preliminary investigation, cast rods 0.09 inch in diameter and five to six inches in length were used; however, with this specimen design it was difficult to produce complete castings without interior porosity. Bush, Ingersoll,

and Peyton developed a threaded enlarged-end specimen design resembling the A.S.T.M. standard specimen but of a size corresponding more closely to dental applications. This specimen, as adapted for this study, consisted of a 0.09 ± 0.01 inch diameter rod, filleted to 12-24 threads at each end (Figure 1). Wax patterns were made at the National Bureau of Standards and distributed to the various laboratories which prepared specimens for use in the investigation. The specimens were cast according to the method normally employed in each laboratory. The resulting castings were then submitted to the National Bureau of Standards where all testing was done. Except for Alloy F (the European product), castings were made by the manufacturers of each alloy, the Central Dental Laboratory of Walter Reed Army Medical Center, Fifth Army Central Dental Laboratory at Saint Louis, Dental Division of the 7100th USAF Hospital, and the Dental Research Section of the National Bureau of Standards.

The tensile properties were determined on a 2000-pound capacity pendulum-type testing machine. The head speed employed was 0.02 inch per minute on the driven head, equivalent to a loading rate of 12,500 psi/min. in the elastic range. The strain was read from two Tuckerman optical strain gages by means of an autocollimator. Figure 2 shows the tensile specimen in the testing machine grips with the Tuckerman gages mounted opposite each other.

A load, approximately equivalent to a stress of 10,000 psi, was applied to the specimen and the strain read. The load was then increased to that equivalent to 50,000 psi and the strain again recorded. Thereafter the load was applied continuously and the strain was recorded at 25 pound load increments (approximately 4,000 psi) up to 500 pounds. The gages were then removed and loading was resumed at the same rate until the specimen failed.

The modulus of elasticity was calculated on the basis of the total strain between the stresses of 10,000 and 50,000 psi.

The yield strength, for purposes of this study, was defined as the higher stress of the first stress increment (approximately 4,000 psi) that produced a strain equal to or greater than 1.25 times that produced by an equal increment below 50,000 psi.

A one-inch gage length was used for the determination of the percent elongation. The length between the gage marks was measured to the nearest 0.002 inch both before testing and after reassembly following fracture.

The Rockwell 30N hardness was determined on specimens of the type used for the tensile test. Parallel flats were wet ground on opposite sides of the specimen. The use of a coolant during the grinding operation is essential in order to avoid changes in the hardness that otherwise would result

from the heat produced by the grinding. The brale indenter and 30 kg load employed in the Rockwell 30N test produce small enough indentations to allow a series of indentations along the longitudinal axis of the ground specimen in both the threaded and the rod portions. A study was made of the relative hardness so determined on specimens as cast and on the fragments of the specimens broken in the tensile test.

These materials, like most alloys, exhibit a melting range rather than a definite melting point. Because these alloys are to be cast, the liquidus temperature, the lowest temperature at which they are completely liquid, is of practical importance. Liquidus temperatures were determined using samples of approximately 35 grams of the alloy. These materials react very rapidly with oxygen at high temperatures and it is necessary to protect them during the prolonged heating required for accurate determinations. Commercial practice employes protective slags and short melting cycles, neither of which could be employed in this case. Since contamination can also occur from the refractories, they must be selected with care. Graphite, for example, must be excluded from the system to prevent the absorption of carbon by reaction with carbide-forming components. Vacuum melting was found to be superior to controlled atmospheres of nitrogen or argon in supplying the melt with the surface protection that slags provide in commercial melting practice.

The melting was done in a high frequency induction furnace which permitted rapid heating and produced a stirring action

which assisted in maintaining the homogeneity of the molten metal. The chrome-cobalt alloy in small ingots was held in a 19 mm o.d. x 90 mm alundum thimble. This was enclosed in a 35 mm i.d. Pyrex envelope and the intervening space was filled with 90 mesh alundum powder (Figure 3). The upper portion of the tube held a platinum-platinum rhodium thermocouple coiled and weighted in such a manner as to allow the protection tube containing the hot junction to move downward as the metal melted. An alundum plug covered the top of the thimble and acted as a guide through which the protection tube passed. The thermocouple passed through a seal in the upper portion of the glass to an ice-bath cold junction, and the resulting potential was measured on a potentiometer readable to 0.001 millivolt (Figure 4). The liquidus temperature was obtained from several cooling curves on each of two or more specimens of each alloy. The thermocouple was calibrated at the freezing points of copper and of Mond nickel.

3. DISCUSSION OF RESULTS

The physical properties of cast tensile specimens are dependent upon many factors and show considerable variation among the alloys tested. The resultant stress-strain curve, however, is typical of most non-ferrous materials. Figure 5, taken from a representative test of a clinically acceptable alloy, shows the generally favorable properties attained with these alloys. The modulus of elasticity was about 28,500,000 psi, which is

approximately twice that of gold alloys. The yield strength was about 70,000 psi and, since no constant stress yielding was observed, some arbitrarily selected method must be chosen for its calculation. The method employed (see above) was one that has been used for cast gold alloys (5). The tensile strength was approximately 105,000 psi.

In addition to the variation in properties that occurs between different alloys, considerable variation can occur in the measured properties for a single alloy when cast under different conditions. Table 2 shows the range of values obtained on alloy A for rod specimens cast by the manufacturer, and for threaded specimens cast by three separate laboratories each using their own techniques and procedures. The observed variation probably results from such factors as burn-out procedure, sprue size and arrangement, and melting and casting technique. Similar variation in the properties of alloy B are shown in Table 3. In this case, the difference in modulus of elasticity for individual specimens is particularly noteworthy. This property normally is not affected much by variations in processing but, in these two lots of castings, the individual modulus values ranged from 23.1×10^6 to 33.1×10^6 psi. This has been attributed to a tendency for this alloy to form grains approximating the diameter of the specimen used in this study. The wide range in the results can then be explained on the basis of anisotropy of the individual grains and their orientation relative to the specimen axis.

Table 4 gives the data for six alloys tested. All values were determined as described above except those for alloy F which were determined in accordance with the proposed specification (6) for these products. This specification employs a combined test for yield strength and modulus of elasticity similar to that in the Federal and American Dental Association specifications for casting golds (7, 8). As a result, the reported value of 60,000 psi yield strength is a minimum value only and the 29.0 x 10^6 psi modulus is a minimum value which is exact only if none of the specimens tested had proportional limits below 60,000 psi.

The composition of alloys E and F as given in Table 1 are those reported by the manufacturers. Chemical composition for alloys A - D was determined by analyses made on the specimens employed in the tensile tests, and represent the composition of the metal actually cast rather than that of the alloy as received from the manufacturer. Considering the melting practices employed, however, the differences are expected to be small. The analytical methods employed are described in references 9, 10 and 11. No attempt was made to make any correlation of the observed properties with composition. The number of compositions tested was small in relation to the number of elements present, so such a correlation would be of little value. In addition, there is good evidence in the results that other factors are of equal or greater importance. Examination of Table 1 shows that alloys D and E are of very similar composition, while Table 4 shows extreme variation in their properties, tensile strength and percent elongation in particular.

Rockwell Superficial Hardness (30N) was determined for each alloy along the entire length, both rod and threaded portions, of specimens used in the tensile test. This aided in the comparison of various spruing arrangements in regard to their ability to prevent formation of shrinkage porosity. As can be noted from Table 4, the results indicated a consistently higher hardness for the rod portion than for the threaded ends. This may be attributed to two possible causes, work hardening of the rod portion during the tensile test, or to structural differences in the two areas resulting from differences in their cooling rates. In order to determine which of these was the proper explanation, a series of hardness tests was performed on specimens which had not been tested in tension. The results are compared with those for previously pulled specimens in Table 5. It can be seen that there is no significant difference between the two groups.

In all probability, the small amount of elongation obtained in these alloys is insufficient to produce work hardening except in the immediate area of fracture. The observed difference in hardness between the rod and threaded portions of the specimens, therefore, is attributed to differences in grain size and distribution of micro-constituents. On the basis of these observations, it is concluded that hardnesses can be determined on the specimens after they have been tensile tested without introducing additional error.

A certain number of specimens were examined metallographically but, aside from the typical dendritic nature of the microstructures, no features were produced with sufficient regularity to permit correlation of structure with observed properties. This lack of correlation is a logical result of the wide range of casting procedures employed by the participating laboratories.

The liquidus temperature of the alloys tested fall into two groups apparently correlated with their cobalt content (Table 6). Alloys B, D, E and F, all containing approximately 60% cobalt, have liquidus temperatures between 2560° and 2650°F; while Alloy A, containing 43.5% cobalt, has a liquidus temperature of 2355°F. Alloy C had been withdrawn from the market, and no sample was available at the time the liquidus temperature determinations were made. The accuracy of the determined values for the liquidus temperature is believed to be within ± 10°F, and to be somewhat better in most cases. In cases where the desirability of greater accuracy would justify the use of larger specimens and greater expenditure of effort the methods reported by Roeser and Wensel (12) are recommended.

4. SUMMARY

The tensile strength, modulus of elasticity, yield strength, percent elongation, superficial hardness, and liquidus temperature were determined for a series of six commercial chromium-cobalt base dental casting alloys. The average tensile properties for these alloys fell within the following ranges: tensile strength 84,500 - 108,500 psi, modulus of elasticity 26.0 -

29.5 x 10^6 psi, yield strength 49,500 - 64,500 psi, and percent elongation 1.9 - 6.0%. The average Rockwell 30N hardness of the alloys tested ranged from 47.0 to 60.0 and their liquidus temperatures ranged from 2355° to 2650°F.

Threaded enlarged-end specimens were found to give more consistent values than straight rods in the tensile test. The rod portion of the threaded specimen was found to be work hardened so little by the tensile test that the same specimen can be employed for the tensile test and the determination of hardness.

BIBLIOGRAPHY

1. Haynes, Elwood, U. S. Patent No. 873,745. December 17, 1907.

2. Personal communication from authors. See also:

   Prange, C, H. U. S. Patent No. 1,909,008. May 16, 1933.
   Erdle, R. W., and Prange, C. H. U. S. Patent No. 1,956,278. April 24, 1934.
   Prange, C. H. U. S. Patent No. 1,958,466. May 15, 1934.

3. Paffenbarger, George C., Caul, H. J., and Dickson, George. JADA 30:852-862 June 1943.

4. Bush, S. H., Ingersoll, C. E., and Peyton, F. A. Navy Contract N6-onr-232 Progress Reports, School of dentistry, University of Michigan.

5. Taylor, N. O., Paffenbarger, George C., and Sweeney, W. T. Inlay Casting Golds: Physical Properties and Specifications. JADA 19:36-53, January 1932.

6. Taylor, Duane F. and Sweeney, W. T. A Proposed Specification for Dental Chromium-Cobalt Casting Alloys. JADA 54:44, January 1957.

7. Federal Specification QQ-G-540, March 1940. Gold; Casting, Inlay, Dental.

8. ADA Specification No. 5: Dental Inlay Casting Golds. ADA Specifications for Dental Materials, July 1956.

9. Hague, John L., Maczkowske, Edwin E., and Bright, Harry A. Determination of Nickel, Manganese, Cobalt, and Iron in High Temperature Alloys, using Anion-exchange Separations. J. Research NBS 53:353, December 1954. Research Paper 2552.

10. Lundell, G. E. F., Hoffman, J. I., and Bright, H. A. Chemical Analysis of Iron and Steel. John Wiley and Sons, Inc., New York, 1931.

11. ASTM Methods of Chemical Analysis of Metals. American Society for Testing Materials, Philadelphia, Pennsylvania, 1950.

12. Roeser, Wm. F., and Wensel, N. T. J. Research NBS. 14:247, 1935. Research Paper 768.

Table 1

Chemical Composition of
Chromium-Cobalt Dental Alloys

Alloy		A[1]	B[1]	C[1]	D[1]	E[2]	F[2]
Cobalt	%	43.5	59.4	29.7	62.6	61.5	65.0
Chromium	%	21.6	30.3	22.3	26.2	27.6	30.0
Molybdenum	%	7.0	5.8	3.3	5.0	5.3	4.0
Nickel	%	20.1	1.5	0.7	2.3	2.3	----
Iron	%	0.25	0.7	40.0	1.0	1.6	----
Silicon	%	0.35	0.55	1.7	0.55	[3]	----
Tungsten	%	-----	0.35	----	1.2	----	----
Manganese	%	3.0	0.34	0.9	0.16	0.8	----
Copper	%	3.5	-----	----	0.20	----	----
Beryllium	%	0.9	----	----	-----	----	----
Carbon	%	0.05	N.D.[5]	N.D.[5]	0.25	[3]	----
Others	%	-----	-----	----	----	1.0[3]	1.0[4]

1 Analyzed at National Bureau of Standards.
2 Reported by Manufacturer.
3 Reported under "Others" as total Si, C, Al.
4 Unspecified additions.
5 No determination.

Table 2

MECHANICAL PROPERTIES OF ALLOY A
AS CAST BY DIFFERENT LABORATORIES

Type of Specimen	Rod	Threaded		
Laboratory	Manufacturer	CDL-WR[4]	NBS	CDL-St. L.[5]
Number of Specimens	4	10	5	11
<u>Modulus of Elasticity</u>				
Mean Value (psi)	32.5×10^6 [3]	28.0×10^6	28.5×10^6	25.5×10^6
σ [1] (psi)	3.0×10^6	1.0×10^6	2.5×10^6	1.5×10^6
C.V.[2] (percent)	9.0	3.0	8.5	6.5
<u>Yield Strength</u>				
Mean Value (psi)	60,500 [3]	65,000	64,000	64,000
σ (psi)	8,000	4,500	5,500	2,500
C.V. (percent)	13.0	7.0	8.5	4.0

Table 2 (Continued)

Type of Specimen	Rod	Threaded		
Laboratory	Manufacturer	CDL-WR[4]	NBS	CDK-St. L.[5]
Number of Specimens	4	10	5	11
Tensile Strength				
Mean Value (psi)	96,500 [3]	108,000	94,500	115,500
σ (psi)	4,000	7,500	11,500	9,500
C.V. (percent)	4.0	7.0	12.0	8.5
Elongation (1-inch gage length)				
Mean Value (percent)	1.8 [3]	2.9	1.2	4.0
σ (percent)	1.1	1.3	---	2.2
C.V. (percent)	60.0	45.0	---	55.0

1 Standard Deviation.
2 Coefficient of Variation.
3 2-inch gage length.
4 Central Dental Laboratory of Walter Reed Army Medical Center.
5 Fifth Army Central Dental Laboratory at Saint Louis.

Table 3

MECHANICAL PROPERTIES of ALLOY B
As Cast by Different Laboratories

Threaded Specimens

Laboratory		CDL-WR[3]	Manufacturer
Number of Specimens		8	9
Modulus of Elasticity			
Mean Value	(psi)	31.0×10^6	28.0×10^6
σ [1]	(psi)	1.2×10^6	2.5×10^6
C. V. [2]	(percent)	3.5	9.0
Yield Strength			
Mean Value	(psi)	65,500	57,000
σ	(psi)	4,500	3,500
C. V.	(percent)	7.0	6.0
Tensile Strength			
Mean Value	(psi)	117,500	98,000
σ	(psi)	9,500	6,000
C. V.	(percent)	8.0	6.0
Elongation (1-inch gage length)			
Mean Value	(percent)	1.2	4.3
σ	(percent)	0.2	1.7
C. V.	(percent)	18.0	40.0

1 Standard Deviation.

2 Coefficient of Variation.

3 Central Dental Laboratory, Walter Reed Army Medical Center.

Table 4

MECHANICAL PROPERTIES OF CHROMIUM-COBALT DENTAL ALLOYS
AVERAGE OF ALL THREADED SPECIMENS

Alloy		A	B	C
Number of Specimens		26	17	6
Modulus of Elasticity				
Mean Value	(psi)	28.0×10^6	29.5×10^6	26.0×10^6
σ [1]	(psi)	2.0×10^6	2.5×10^6	1.5×10^6
C. V.[2]	(percent)	7.0	8.0	6.5
Yield Strength				
Mean Value	(psi)	64,500	61,000	49,500
σ	(psi)	4,500	7,000	8,000
C. V.	(percent)	7.0	11.5	16.5
Tensile Strength				
Mean Value	(psi)	108,500	107,500	104,000
σ	(psi)	12,000	12,500	8,500
C. V.	(percent)	11.0	11.5	8.0
Elongation (1-inch gage length)				
Mean Value	(percent)	3.4	3.2	2.7
σ	(percent)	1.9	2.1	1.5
C. V.	(percent)	55.0	65.0	56.0

1 Standard Deviation.

2 Coefficient of Variation.

Table 4 (Continued)

Alloy	D	E	F
Number of Specimens	5	18	9
Modulus of Elasticity			
Mean Value (psi)	27.5×10^6	28.5×10^6	29.0×10^6
σ [1] (psi)	2.5×10^6	3.5×10^6	1.0×10^6
C. V.[2] (percent)	9.5	12.0	4.0
Yield Strength			
Mean Value (psi)	56,000	62,400	60,000+[3]
σ (psi)	4,000	3,000	----
C. V. (percent)	7.0	5.0	----
Tensile Strength			
Mean Value (psi)	84,500	102,500	105,100
σ (psi)	4,000	10,000	6,500
C. V. (percent)	5.0	10.0	6.0
Elongation (1-inch gage length)			
Mean Value (percent)	6.0	1.9	1.9
σ (percent)	2.9	0.8	0.9
C. V. (percent)	48.0	40.0	47.0

3 Minimum value determined in accordance with proposed specification.

Table 4 (Continued)

Alloy	No. of Specs.	Hardness (R 30N)		
		Mean Value	σ	C. V. (percent)
A	26			
a		53.0	2.0	4.0
b		47.0	4.5	9.5
B	17			
a		60.0	1.0	2.0
b		57.0	1.5	2.5
C	6			
a		54.0	1.5	3.0
b		49.0	1.0	2.0
D	5			
a		51.0	1.0	2.0
b		49.0	1.5	3.0
E	18			
a		55.0	0.5	1.0
b		51.0	1.0	2.0
F	9			
a		58.0	1.5	2.5

a Rod portion.

b Threaded portion.

Table 5

EFFECT OF PRIOR TENSILE TESTING ON HARDNESS

	As Cast		After Tensile Test	
Alloy	Rod Portion	Threaded Portion	Rod Portion	Threaded Portion
A	53.0	47.0	54.0	52.0
B	60.0	57.0	60.0	60.0
C	54.0	49.0	50.0	48.0
E	55.0	51.0	54.0	53.0

All values are average Rockwell 30N hardness.

Table 6

Liquidus Temperature of
Chromium-Cobalt Dental Alloys

Alloy	Liquidus °F
A	2355
B	2605
D	2575
E	2650[1]
F	2560

1 As reported by manufacturer.

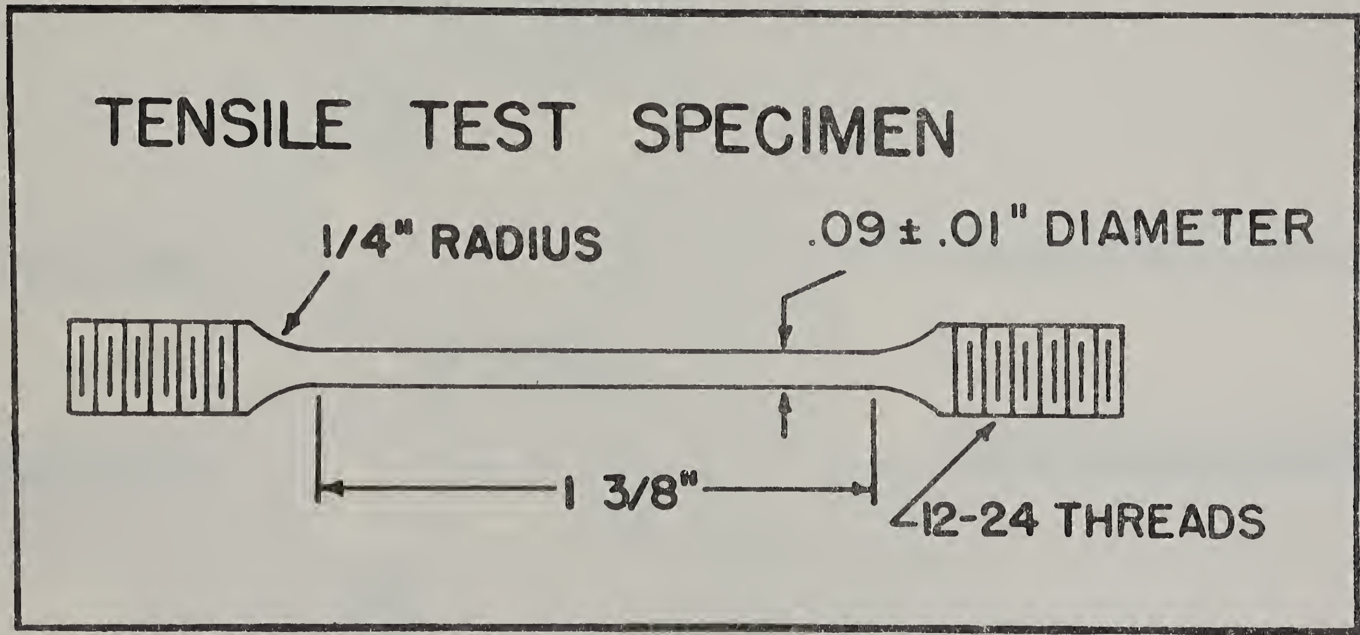

Figure 1. Specimen design for tensile test

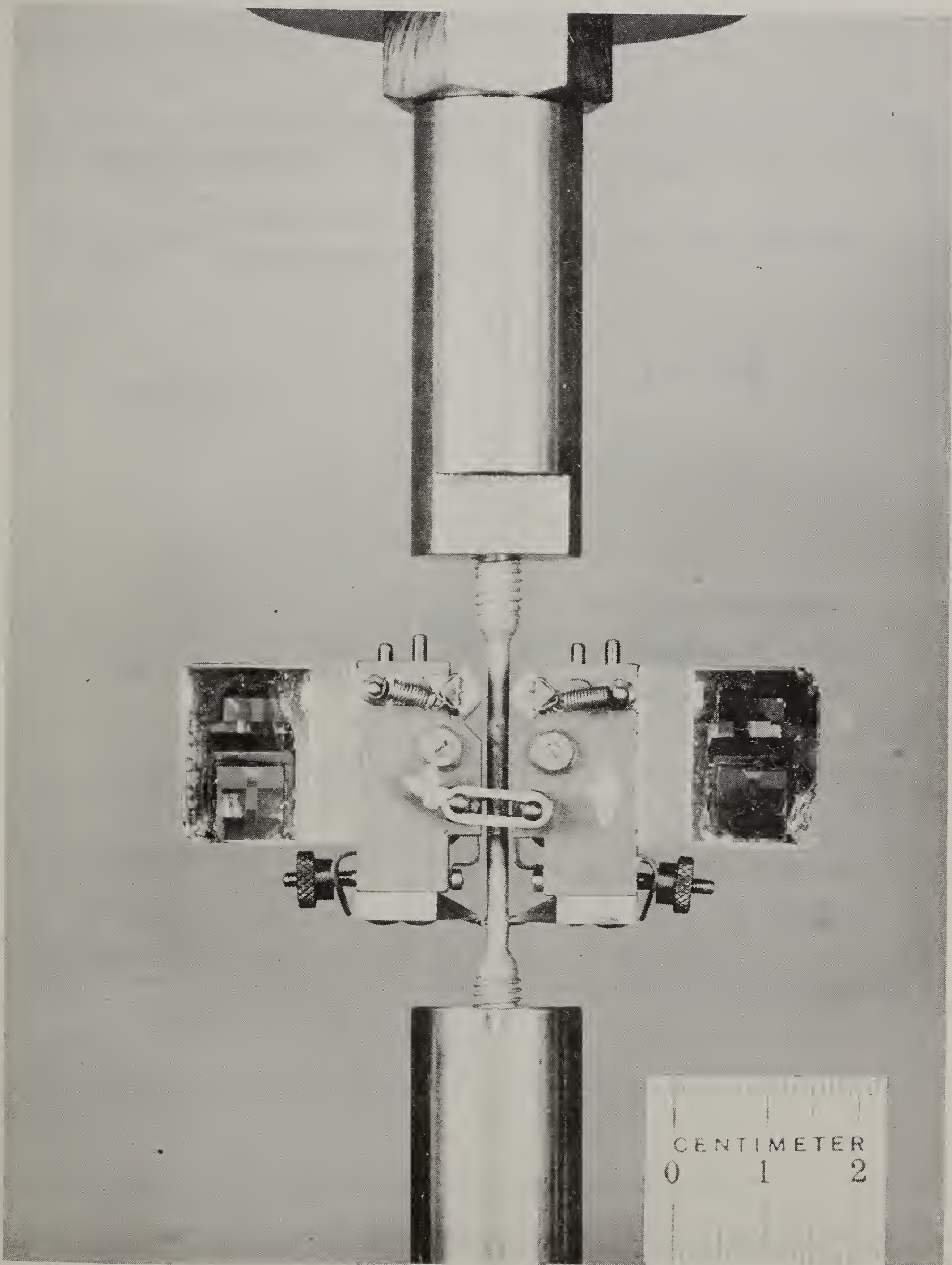

Figure 2. Tensile specimen in testing machine grips showing mounting of strain gages.

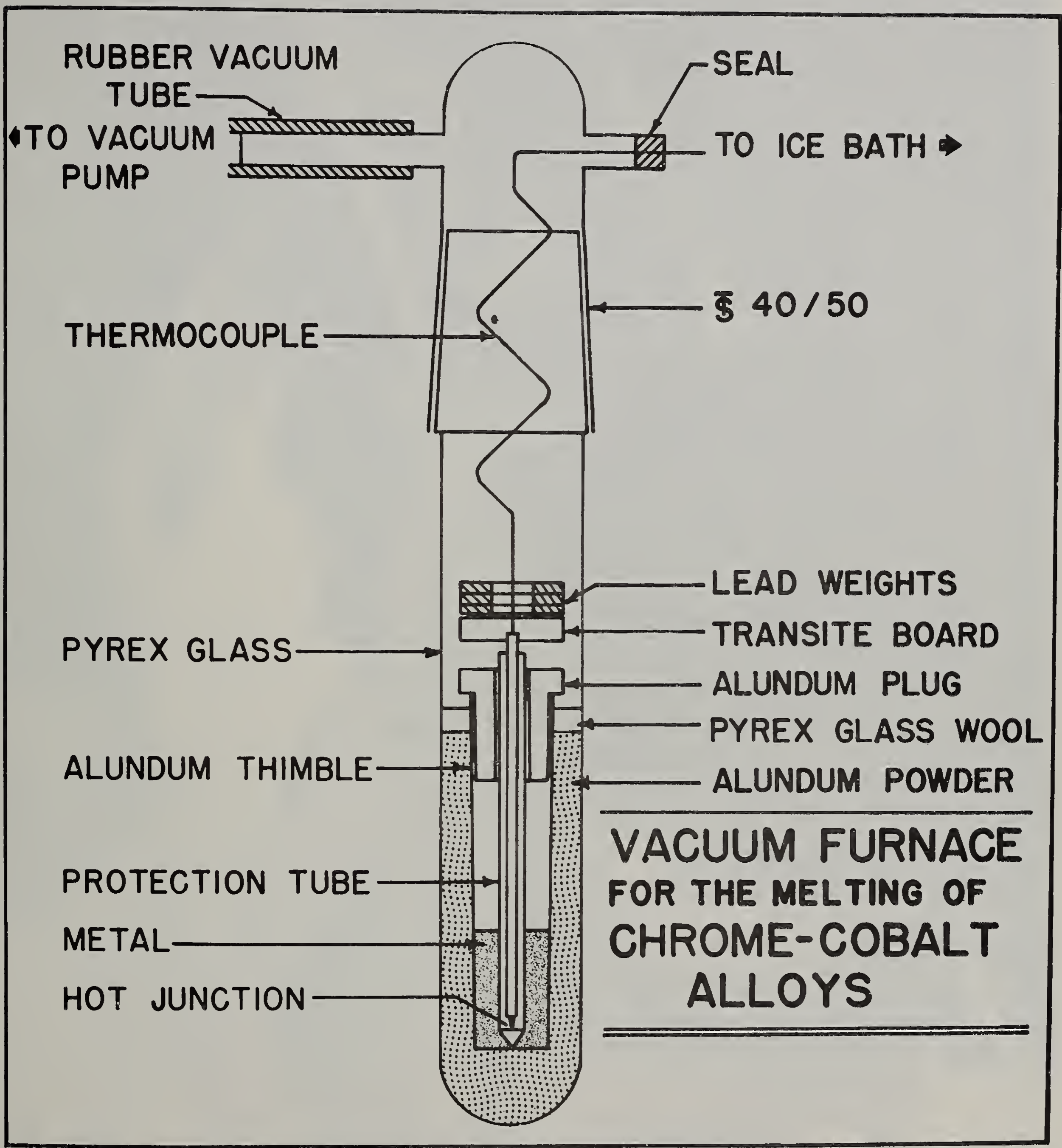

Figure 3. Schematic drawing of vacuum furnace for the induction melting of small specimens.

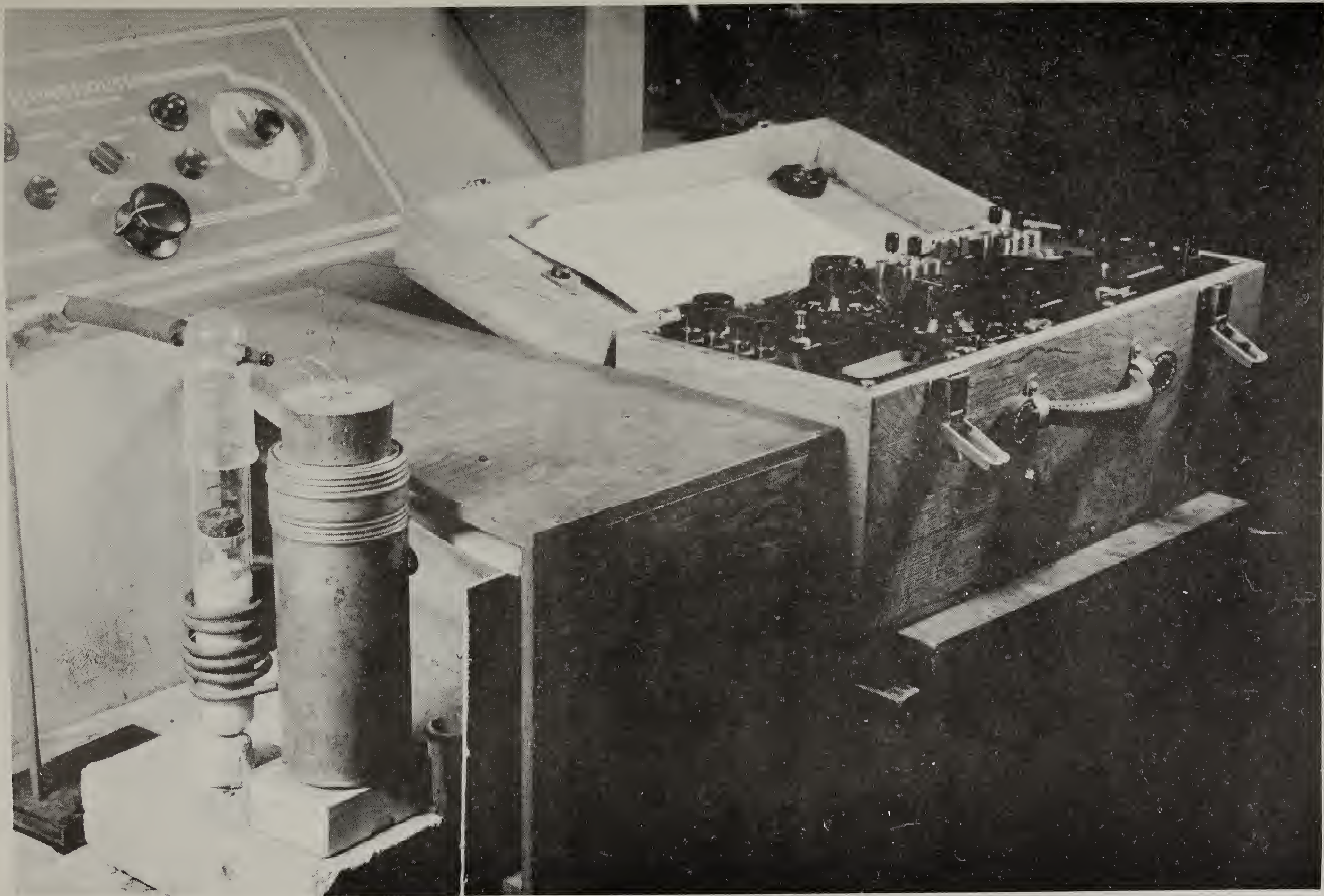

Figure 4. Apparatus employed for liquidus temperature determinations.

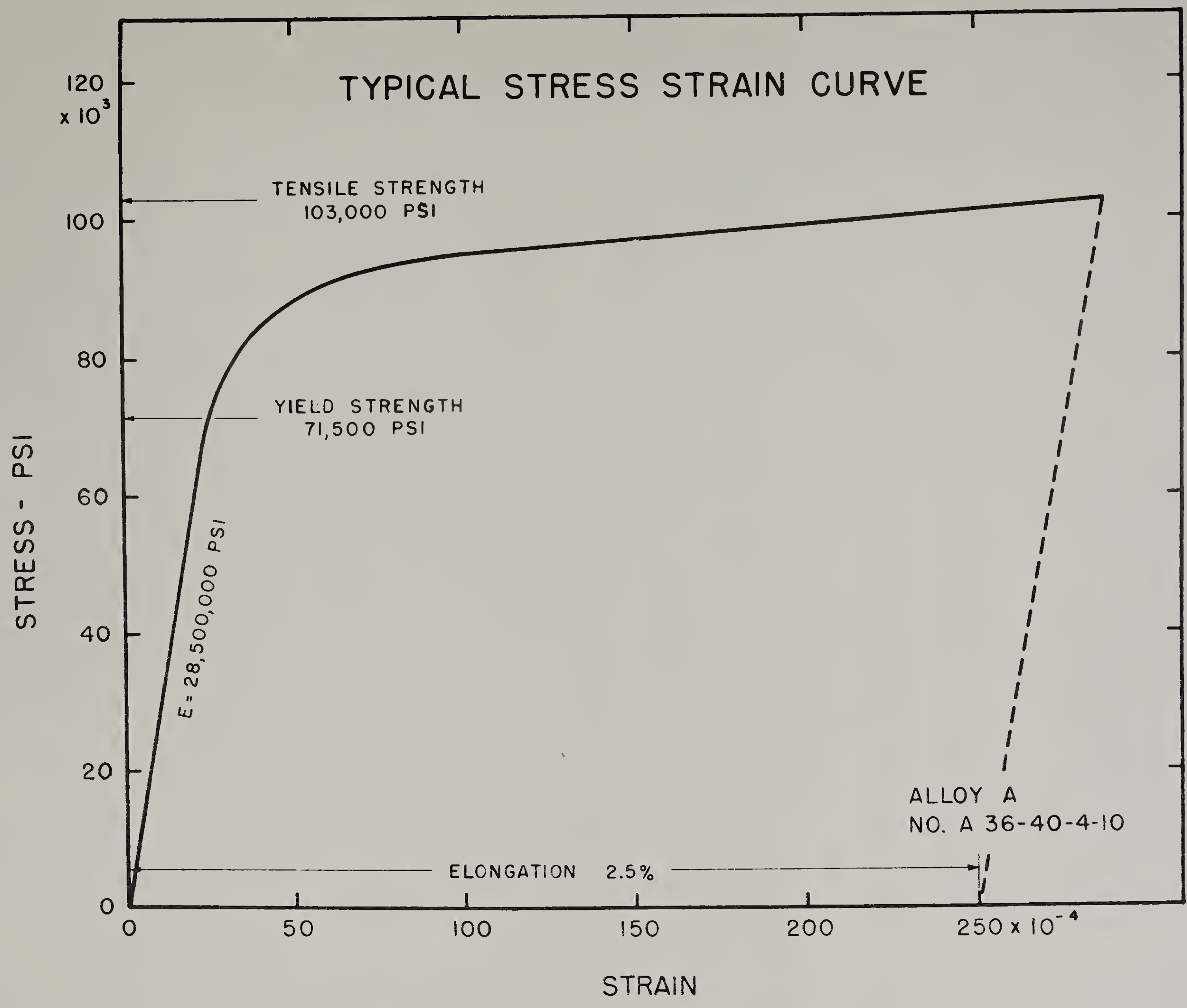

Figure 5. Stress-strain curve for typical tensile specimen.

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THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside front cover of this report.

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Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

NBS