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THERMAL EXPANSION OF BEARING BRONZES

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ABSTRACT

This paper gives data on the linear thermal expansion of cast bearing bronzes (copper-tin and copper-tin-lead alloys) at various temperatures between 20 C (68 F) and 200 C (392 F). The results obtained on heating and cooling are shown in figures 1 and 2. Coefficients of expansion for various temperature ranges are given in table 2. The coefficients of expansion obtained in the second tests are generally higher than those obtained in the first tests. The addition of tin to copper, or lead to copper-tin alloys increases the coefficients of expansion. Equations were derived which show the relationship between the tin content and the coefficients of expansion of cast copper-tin alloys and between the lead content and the coefficients of expansion of cast leaded bronzes with a copper-tin ratio equal to about 7.

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I. INTRODUCTION

Data on the linear thermal expansion of bearing bronzes have been published¹ in 1921. A supplementary investigation on the linear thermal expansion of bearing bronzes was recently undertaken in order to supply a demand for data on various cast bronzes and cast leaded bronzes that have not been investigated previously. Measurements were made of the thermal expansion of these alloys at various temperatures between 20 and about 200 C. The effect of tin in the binary alloys and the effect of lead in the ternary alloys were determined.

Bronze and leaded bronze bearings are found in many types of machines. The comparatively high melting points and strength of these alloys make them more suitable for certain purposes than the weaker and lower melting point white metals. Leaded bronzes find

¹ Hidnert, Thermal Expansion of Copper and Some of Its Important Industrial Alloys, B.S. Scientific Paper 410.

wide applications on railroads, in the automotive industry, and in stationary machinery. Information about the physical properties² including thermal expansion, at normal and elevated temperatures which these alloys can safely stand, is therefore important.

The Bunting Brass & Bronze Co., Toledo, Ohio, furnished the samples of bearing bronzes and information about the preparation and the chemical composition. The author wishes to express his appreciation for the cooperation by this company and by C. E. Eggenschwiler, formerly research metallurgist for this company. Acknowledgment is also due to the following members of the staff of the Bureau: H. W. Bearce, W. Souder, H. S. Rawdon, and C. G. Peters for valuable suggestions, to H. S. Krider for assistance during the measurements, and to S. Alpher for aid in the preparation of the figures.

II. MATERIALS INVESTIGATED

Table 1 indicates the chemical composition of the samples of bearing bronzes which were investigated. Each sample was 300 mm in length and 9 mm in diameter. Samples 1472 to 1477, inclusive, were made of virgin materials and the remaining samples from commercial materials. All samples except 1477 were cast between 2,100 and 2,150 F into green sand molds. Sample 1477 was poured at 2,000 F. The melting was done in a gas-fired furnace. Bars from which the samples were cut, were cast in the horizontal position and were gated at the ends of the bars.

TABLE 1.—Chemical composition of bearing bronzes

Sample	Chemical composition						
	Copper	Tin	Lead	Nickel	Phosphorus	Zinc	Antimony
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1472	99.20				0.04	0.76	
1473	87.75	12.25			.02		
1474	83.80	11.96	4.22		.02		
1475	77.00	11.08	11.90		.02		
1476	69.82	9.72	20.50		.02		
1477	65.40	7.75	26.62	0.25		None	Trace
1478	95.70	1.95	2.32		.03		
1479	75.86	11.57	12.00	.20	.04	.25	0.15
1480	80.02	9.58	9.45	.15	.04	.60	.15
1481	82.28	6.70	7.48	.15	.05	3.20	.15
1482	88.63	8.58	2.08	.25		.34	.15
1483	86.75	9.97	.53		.03	2.75	
1484	73.00	4.45	21.79	.35	.05	.25	.15

III. APPARATUS

The apparatus described in B.S. Scientific Paper 410 was used for the determinations of linear thermal expansion.

IV. RESULTS

Observations were made on the linear thermal expansion of the bearing alloys at various temperatures between 20 and about 200 C. The results obtained on heating and cooling are shown in figures 1 and 2. The expansion curves are plotted from different origins in order to show the individual characteristics of each curve.

² W. M. Corse, Bearing Metals and Bearings, American Chemical Society Monograph No. 53, 1930, gives a history of bearing metals and bearings, literature references from 1900 to 1928, abstracts of selected papers, and tables showing properties of bearing metals.

FIGURE 1.—Linear thermal expansion of cast bearing bronzes (samples 1472 to 1478).

FIGURE 2.—Linear thermal expansion of cast bearing bronzes (samples 1479 to 1484).

The observations on cooling in the first test were, in most cases, below the expansion curves obtained on heating in the first test. Tests were repeated on a number of samples, especially in cases where the observations on cooling in the first test did not lie close to the expansion curve on heating. The results obtained on the first heating apply for cast samples as received, but the results obtained in the second tests apply for heat-treated or annealed samples.

The average coefficients of expansion given in table 2 were computed from the expansion curves in figures 1 and 2. The coefficients of expansion obtained in the second tests are generally higher than those obtained in the first tests. Table 2 also shows the difference in length before and after each expansion test. The plus (+) sign indicates an increase in length and the minus (−) sign a decrease in length.³

TABLE 2.—Average coefficients of linear expansion of bearing bronzes

Sample	Chemical composition ¹			Test no.	Average coefficients of expansion per degree centigrade				Average coefficients of expansion per degree Fahrenheit ²				Change in length after heating and cooling
	Copper	Tin	Lead		20 to 60 C	20 to 100 C	20 to 150 C	20 to 200 C	68 to 140 F	68 to 212 F	68 to 302 F	68 to 392 F	
	Per-cent	Per-cent	Per-cent		$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$	Percent
1472 ³	99.20			1	16.7	16.9	17.2	17.4	9.3	9.4	9.6	9.6	0.000
1473	87.75	12.25		1	17.6	17.7	18.0	18.1	9.7	9.8	10.0	10.1	−.000
1474	83.80	11.96	4.22	1	17.4	17.9	18.1	18.3	9.7	9.9	10.0	10.1	−.002
1475	77.00	11.08	11.90	1	17.7	18.6	18.5	18.6	9.8	10.3	10.3	10.3	−.003
				2	18.4	18.5	18.7	18.8	10.2	10.3	10.4	10.4	−.000
1476	69.82	9.72	20.50	4 ¹	18.6	18.6	18.6	18.8	10.4	10.3	10.3	10.4	−.005
				2	18.9	18.9	19.0	19.1	10.5	10.5	10.5	10.6	−.000
1477	65.40	7.75	26.62	5 ¹	19.0	19.0	18.9	19.0	10.6	10.6	10.5	10.6	−.009
				2	18.8	19.1	19.3	19.4	10.5	10.6	10.7	10.8	−.001
1478	95.70	1.95	2.32	1	17.1	17.2	17.3	17.3	9.5	9.5	9.6	9.6	−.001
				2	17.0	17.1		17.6	9.4	9.5		9.8	−.000
1479	75.86	11.57	12.00	1	17.9	18.3	18.6	18.7	10.0	10.2	10.3	10.4	−.005
1480	80.02	9.58	9.45	1	18.0	18.4	18.4	18.6	10.0	10.2	10.2	10.3	−.003
1481 ⁶	82.28	6.70	7.48	1	17.7	18.1	18.2		9.8	10.1	10.1		−.002
				2	17.8	18.0	18.2	18.4	9.9	10.0	10.1	10.2	−.001
1482	88.63	8.58	2.08	1	17.2	17.5	17.6	17.9	9.6	9.7	9.8	9.9	−.003
				1	17.6	17.8	18.1		9.7	9.9	10.1		+ .000
1483 ⁷	86.75	9.97	.53	2	17.8				9.9				−.000
				3	17.5	17.8	18.0		9.7	9.9	10.0		−.000
				4	17.6	17.9	18.1	18.3	9.8	9.9	10.1	10.2	−.000
1484	73.00	4.45	21.79	5 ¹	18.4	18.9	18.8	18.8	10.2	10.5	10.5	10.5	−.007
				2	18.7	19.2	19.2	19.2	10.4	10.6	10.6	10.7	−.000

¹ See table 1 for complete chemical composition.

² The coefficient of expansion per degree Fahrenheit is equal to 5/9 of the coefficient of expansion per degree centigrade.

³ Zinc 0.76 percent.

⁴ On cooling, the average coefficient of contraction is 19.0×10^{-6} between 200 and 20 C and 18.2×10^{-6} between 100 and 20 C.

⁵ On cooling, the average coefficient of contraction is 19.5×10^{-6} between 200 and 20 C and 18.8×10^{-6} between 100 and 20 C.

⁶ Zinc 3.20 percent.

⁷ Zinc 2.75 percent.

⁸ On cooling, the average coefficient of contraction is 19.2×10^{-6} between 200 and 20 C and 18.8×10^{-6} between 100 and 20 C.

³ After an examination of table 2, C. E. Eggenschwiler made the following comments: "It was especially interesting to observe the rather progressive shortening of the test specimens' length at the end of the first heating, as the lead content increased. Also to note that the second heating tests did not show this condition." He also stated that the results seem to indicate that the alloys are more compact after the first heating. This has been verified by density measurements made by S. Alpher of this Bureau on duplicate samples of 1476, 1477, and 1484, before and after heating to 200 C and cooling to 20 C. The results obtained are as follows:

Sample	Density before heating	Density after heating and cooling
1476 A	9.028 g/cm ³	9.031 g/cm ³
1477 A	9.362	9.366
1484 A	8.951	8.954

Table 3 shows that the coefficients of expansion of sample 1472 which contains 99.20 percent copper and 0.76 percent zinc, are slightly larger than the coefficients of expansion of electrolytic copper containing 99.97 percent copper. It has been shown in a previous publi-

FIGURE 3.—Effect of additions of tin on the average coefficients of linear expansion of cast copper-tin alloys.

A tagged symbol indicates more than one value.

cation ⁴ that the addition of zinc to copper causes an increase in the coefficients of expansion.

TABLE 3.—Comparison of coefficients of expansion of copper and copper-zinc alloy

Material	Average coefficients of expansion per degree centigrade			
	20 to 60 C	20 to 100 C	20 to 150 C	20 to 200 C
Sample 1472, cast copper-zinc alloy.....	$\times 10^{-6}$ 16.7	$\times 10^{-6}$ 16.9	$\times 10^{-6}$ 17.2	$\times 10^{-6}$ 17.4
Electrolytic copper, hot rolled ¹	16.6	16.8	17.0	17.3
Electrolytic copper, hot rolled and drawn ¹	16.6	16.8	17.0	17.2

¹ Hidnert, B.S. Scientific Paper 410.

Table 4 and figure 3 show coefficients of expansion of cast copper-tin alloys. From these coefficients of expansion, the following equations were derived by the method of least squares:

$${}_{20}a_{100} = (17.03 + 0.0646 Sn) 10^{-6} \quad (1)$$

$${}_{20}a_{200} = (17.47 + 0.0565 Sn) 10^{-6} \quad (2)$$

where ${}_{20}a_{100}$ represents the average coefficient of expansion between 20 and 100 C, ${}_{20}a_{200}$ represents the average coefficient of expansion between 20 and 200 C, and Sn represents the percentage of tin. These equations show that the coefficients of expansion of copper-tin alloys increase with increase in the tin content.

⁴ Hidnert, B.S. Scientific Paper 410.

TABLE 4.—Coefficients of expansion of cast copper-tin alloys

Chemical composition		Average coefficients of expansion per degree centigrade	
Copper	Tin	20 to 100 C	20 to 200 C
Percent	Percent	$\times 10^{-6}$	$\times 10^{-6}$
¹ 99.97		16.8	17.3
		17.4	17.8
² 95.40	4.25	17.5	17.9
		³ 17.3	³ 17.7
		17.4	17.8
		17.4	17.7
² 94.86	4.88	17.3	17.7
		17.4	17.8
		17.2	17.6
		17.5	17.9
² 92.04	7.67	17.5	17.9
		17.5	17.8
		17.6	17.9
		17.6	18.1
² 89.69	10.14	17.5	18.0
		17.8	18.1
		17.8	18.2
⁴ 87.75	12.25	17.7	18.1
⁵ 84.84	14.95	18.0	18.2

¹ Electrolytic copper, hot rolled. See Hidnert, B.S. Scientific Paper 410.

² Four samples (inside and outside sections) cut from casting. See Hidnert, B.S. Scientific Paper 410.

³ Result on second heating.

⁴ Sample 1473, present investigation.

⁵ Hidnert, Physical Review, vol. 39, p. 551, 1932.

Figure 4 shows that additions of lead increase the coefficients of expansion of cast bearing bronzes with a copper-tin ratio equal to about 7. The following equations which show the relationship between the coefficients of expansion and the lead content of the bearing alloys were derived by the method of least squares from the data shown in figure 4:

$${}_{20}a_{100} = (17.76 + 0.0475 Pb) 10^{-6} \quad (3)$$

$${}_{20}a_{200} = (18.16 + 0.0355 Pb) 10^{-6} \quad (4)$$

In these equations, ${}_{20}a_{100}$ represents the average coefficient of expansion between 20 and 100 C, ${}_{20}a_{200}$ represents the average coefficient of expansion between 20 and 200 C, and Pb represents the percentage of lead between 0 and 20.50 percent. Table 5 gives coefficients of expansion which were computed from equations (3) and (4).

TABLE 5.—Effect of lead on the coefficients of linear expansion of cast bearing bronzes with a copper-tin ratio equal to about 7

Lead	Average coefficients of expansion per degree centigrade	
	20 to 100 C	20 to 200 C
Percent	$\times 10^{-6}$	$\times 10^{-6}$
0	17.8	18.2
4	17.9	18.3
8	18.1	18.4
12	18.3	18.6
16	18.5	18.7
20	18.7	18.9

Figures 5 and 6 show the coefficients of expansion of cast copper-tin alloys and cast copper-tin-lead alloys for the range from 20 to 100 C and from 20 to 200 C, respectively. These figures indicate that the addition of tin to copper, or lead to copper-tin alloys increases the coefficients of expansion. The addition of about 3 percent zinc to two copper-tin-lead alloys (samples 1481 and 1483) does not appear to have an appreciable effect on the coefficients of expansion. With

FIGURE 4.—Effect of lead on the average coefficients of linear expansion of cast bearing bronzes with a copper-tin ratio equal to about 7.

The tagged symbol indicates the same value for both temperature ranges.

the aid of figures 5 and 6, it is possible to predict the coefficients of expansion of other neighboring alloys that have not been investigated.

V: CONCLUSIONS

1. The expansion curves in the first heating of cast bronzes are in most cases above the observations obtained in the first cooling.

2. The coefficients of expansion obtained in the second heating are generally higher than those obtained in the first heating.

3. The addition of tin to copper, or lead to copper-tin alloys increases the coefficients of expansion.

4. The following equations show the relationship between the tin content and the coefficients of expansion of cast copper-tin alloys:

$${}_{20}\alpha_{100} = (17.03 + 0.0646 Sn) 10^{-6}$$

$${}_{20}\alpha_{200} = (17.47 + 0.0565 Sn) 10^{-6}$$

In these equations, ${}_{20}\alpha_{100}$ and ${}_{20}\alpha_{200}$ represent the average coefficients of expansion from 20 to 100 C and from 20 to 200 C, respectively, and Sn represents the percentage of tin between 0 and 15 percent.

FIGURE 5.—Portion of triangular diagram indicating the effect of composition on the coefficient of expansion (in millionths per degree C) of cast copper-rich binary and ternary alloys between 20 and 100 C.

FIGURE 6.—Portion of triangular diagram indicating the effect of composition on the coefficient of expansion (in millionths per degree C) of cast copper-rich binary and ternary alloys between 20 and 200 C.

5. The following equations show the relationship between the lead content and the coefficients of expansion of cast leaded bronzes with a copper-tin ratio equal to about 7:

$${}_{20}a_{100} = (17.76 + 0.0475 Pb) 10^{-6}$$

$${}_{20}a_{200} = (18.16 + 0.0355 Pb) 10^{-6}$$

In these equations, ${}_{20}a_{100}$ and ${}_{20}a_{200}$ represent the average coefficients of expansion of leaded bronzes from 20 to 100 C and from 20 to 200 C, respectively, and Pb represents the percentage of lead between 0 and 20.50 percent.

6. With the aid of figures 5 and 6, it is possible to predict the coefficients of expansion of other cast copper-tin and copper-tin-lead alloys.

WASHINGTON, November 14, 1933.