DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

S. W. STRATTON, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS NO. 135

[Issued October 16, 1919]

BEHAVIOR OF WROUGHT MANGANESE BRONZE EXPOSED TO CORROSION WHILE UNDER TENSILE STRESS

By P. D. Merica, Physicist, and R. W. Woodward, Associate Physicist

I. INTRODUCTION

In the course of a previous investigation by the authors[1] of a series of failures by fracturing of brass and bronze bolts it was suspected that many cases of such failure were due not to defective material but to the fact that the bolts had been overstressed in service. Careful examination of these bolts revealed a normal and sound structure and satisfactory mechanical properties; the bolts were comparatively free from initial stresses which would have caused corrosion cracking. No other cause of failure could be well assigned other than that they had actually been overstressed in tightening up.

The question was thus raised, What service stresses may with safety be applied to physically normal wrought brass and bronze of the types ordinarily used for structural purposes? The failed bolts in question had probably not been stressed above from 15 000 to 20 000 pounds per square inch; their tensile strength was about 60 000, their yield point about 30 000 pounds per square inch. The service stresses were thus presumably not above the yield point.

[1] P. D. Merica and R. W. Woodward, Failure of Brass, Technologic Paper No. 82 of the Bureau of Standards; 1917.

120129°—19

Jonson,[2] in a most interesting investigation, showed that brass rods exposed to the action of concentrated ammonium hydroxide and subjected at the same time to the very gradual application of tensile stress would break with little elongation at any values of the stress greater than the yield point of the material. Fracture occurred within from 6 to 20 days.

The effect of combined tensile stress and surface corrosion is to diminish, apparently, the stress at which fracture will occur.

The corrosive action of this solution is very severe, and yet many, including the authors, believed that its action under these conditions was not different in principle, but only more rapid, than that of water or moist air in which brass or bronze bolts might actually be placed in service. It was believed that Jonson's work demonstrated that wrought brass or bronze could be used only for very low stresses and with high factors of safety whenever corrosion was to be expected. In view of the fact that these materials would supplant steel usually only because of their superior resistance to corrosion, the verdict of the work seemed to limit very largely the usefulness of brass and bronze, for structural purposes at least, until more reassuring information concerning their behavior in service might be obtained.

The authors have, therefore, undertaken to discover whether corrosion by water and moist air will produce the same effect in combination with the simultaneous application of tensile stress as that by ammonium hydroxide. Bars of wrought manganese bronze were exposed to corrosion in water and moist air while at the same time under tensile stresses of different values. Although the period of exposure has been to date only two years, it is thought that a report of the behavior of these bars during that relatively short period will be of interest to those using and manufacturing this material.

Since much longer periods than the few days of Jonson's tests were contemplated, small test frames were used for these tests rather than standard tensile-testing machines for the application of tensile stress to the specimens. Twelve such frames were made, in each of which a brass-bar specimen could be placed in tension of any required amount and the value of the stress measured by strain gage measurements on a steel reference bar placed "in series" with the brass-test specimen; that is, such that the same total load was borne by the steel reference bar as by the brass-test bar.

[2] E. Jonson, The Fatigue of Copper Alloys, Proc. Am. Soc. for Testing Materials, **40**, p. 101; 1915.

A sketch of the frame used is shown in Fig. 1.

Each of the frames consists of two blocks of steel, *a a*, which can be braced apart by the two rods *b b*, of which one end is secured by pins *d d* against rotation, while the others fit in the bored holes, *e e*. The brass specimens, as well as the steel reference bars, are threaded at the ends and secured by nuts, *c c*, at the ends and by the coupling nut *i* at the center. A ball and socket joint is provided at *f f* to secure axial loading. The center member of these frames consisting of the steel reference bar and the brass test bar can be placed under a tensile load of any desired value by the adjustment of the nuts *g g* against the block *a*.

The test specimens were cut from ¾ inch round bars; they were 11½ inches long and 0.50 inch in diameter and had standard ¾-inch threaded ends. The steel reference bars for the extensometer measurements were also 11½ inches long, were of two

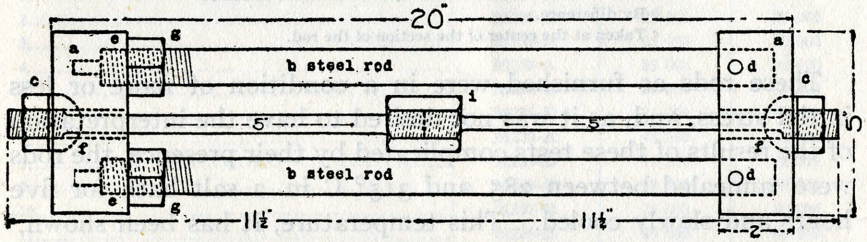

FIG. 1.—*Frame used in the stress-corrosion tests*

diameters, 0.420 and 0.350 inch, and had also standard ¾-inch threaded ends.

An alloy-steel rod kindly furnished by the Midvale Steel Co. was used for the preparation of the steel reference bars. This was heat treated to produce a high elastic limit, and the section of the rod was so chosen as to allow of the utilization of the full elasticity of the rod in each individual measurement of stress.

II. MATERIALS USED FOR TEST

In this first series of tests only one type of brass was used; that is, manganese bronze. The American Brass Co. very kindly furnished ¾-inch round rods of this material in three tempers or degrees of hardness, Nos. M237, M238, and M239, as well as the results of chemical analyses and of mechanical tests of the rods. These data are given in Table 1.

TABLE 1.—Chemical Analysis and Mechanical Properties of the Three Samples of Wrought Manganese Bronze Used in the Tests[a]

	Rods No. M237	Rods No. M238	Rods No. M239
Chemical composition:			
Copper........per cent..	56.64	56.87	56.60
Zinc [b]........do....	40.94	41.07	41.01
Tin........do....	1.26	1.20	1.18
Lead........do....	.12	.08	.11
Iron........do....	.85	.68	.91
Manganese........do....	.19	.10	.19
Mechanical properties:			
Tensile strength........pounds per square inch..	84 700	89 050	101 650
Yield point........do....	44 050	59 550	73 350
Elongation in 2 inches........per cent..	29	22	14
Reduction of area........do....	25	19	10
Brinell hardness [c]........	117	137	158
Scleroscope hardness [c]........	36	43	49

[a] These values were furnished by the American Brass Co.
[b] By difference.
[c] Taken at the center of the section of the rod.

These rods as furnished were in a condition of more or less initial stress, and, as it was not desired to have the interpretation of the results of these tests complicated by their presence, the rods were annealed between 285 and 315° C in a salt bath for five hours and slowly cooled. This temperature, it has been shown,[3] is sufficient to relieve initial stress in manganese bronze, but does not markedly soften the material.

Determination of the proportional limit of a bar of each group after this annealing showed the following results:

Manganese bronze rods	Proportional limit
	Lbs./in.²
No. M237........	25 000
No. M238........	35 000
No. M239........	42 500

The modulus of elasticity of all of the bars was appreciably the same; that is, 16 000 000 pounds per square inch.

III. PROCEDURE OF TEST

From each group of brass rods of the same temper were prepared four test specimens. These were placed in the frames and tensile stresses of different values, given in Table 2, applied to

[3] Loc. cit.

them. Nine test specimens—that is, three of each group—were exposed to corrosion. Of each group one specimen was stressed just to the proportional limit, one was stressed to a value of the stress just above the proportional limit, and one to a value just below it. Three test specimens, one of each group, were stressed just to the proportional limit, and then covered with paraffin as a protection against corrosion; these specimens were preserved as comparison specimens in the laboratory during the period of test.

TABLE 2.—Proportional Limits of the Test Specimens and Approximate Test Stresses Applied to Them

Frame	Specimen	Proportional limit	Approximate test stress
		Lbs./in.^{2}	Lbs./in.^{2}
1	M237–A	25 000	15 000
2	M237–C	25 000	25 000
3	M237–D	25 000	30 000
4	M238–A	35 000	20 000
5	M238–C	35 000	35 000
6	M238–D	35 000	40 000
7	M239–A	42 500	25 000
8	M239–B	42 500	42 500
9	M239–C	42 500	47 500
10	M237–B	25 000	30 000
11	M238–B	35 000	40 000
12	M239–D	42 500	45 000

For the measurement of stress a 5-inch strain gage reading to 0.0001 inch was used, and on each bar two sets of holes for the gage points were placed on opposite sides. The difference in the strain-gage reading before and after loading the bars by tightening up the nuts *g g*, or unloading by loosening the nuts, allowed of the calculation of the applied stress. That the stresses were applied approximately axially is shown by the fact that the extensions of the two opposite fibers of each bar usually agreed in value within less than 5 per cent; in a few cases the agreement was only within 10 per cent.

The average value of the extensions on the two opposite sides was used in the calculation of stress.

After applying the desired stresses to all of the specimens in the frames, they were allowed to lie for a few days and were then regaged. Only insignificant changes in length and consequently of stress had occurred in that time. The frames were then wrapped in cloth and painted with red lead and the steel reference bars covered with a layer of paraffin as a protection against corrosion. All gage-point holes were also carefully wrapped with cloth and paraffined. The portion of the brass test specimens in frames 1 to 9 between gage-point holes was left bare and unprotected; the test specimens in the frames 10 to 12 were paraffined.

IV. EXPOSURE OF TEST FRAMES

The frames 1 to 9, inclusive, were then placed near the top of a water surge tank in the engine room, such that they were alternately immersed in water and exposed to the air. Frames 10, 11, and 12 were laid away in the laboratory. This was done on December 22, 1916. On March 2, 1917, the frames were removed and examined. No cracks or fractures had appeared; the brass had tarnished badly. On March 13 the tensile stress on each test specimen was relieved and measured; on March 15 the test stress was again applied, measured, and on April 6 the frames were put back in the tank. On June 12 they were again removed and examined. No cracks had appeared, but the corrosion had progressed, and the surfaces of the bronze bars were of a greenish-brown color. The frames were placed by error at this time outside the tank and were exposed to the fumes and smoke of the boiler room, but they remained fairly dry. On October 10, 1917, the frames were replaced in the tank. On March 4, 1918, the frames were removed for examination. The specimen No. M239–B in frame 8 had fractured, evidently quite recently, judging by the brightness of the fractured surfaces. Fig. 2 shows the appearance of this frame and specimen after fracture. The other specimens were quite sound. All of the frames except No. 8 were replaced in the tank on March 10. On December 30, 1918, upon searching for these frames, it was discovered that about August 1 they had been removed from the tank by the plumbers and placed back of it. When found, frames Nos. 2, 6, and 9 were entirely immersed in dirty water; Nos. 3, 4, and 5 were partially immersed, lying on top of the others. Nos. 1 and 7 were in another location, which was dry at the time of examination. The latter frames were quite dirty, as were, indeed, all of the frames, being covered with black mud, and they had evidently been in the water or had been sprayed with water from the hose while in that location.

All of the brass specimens after washing off the mud showed that they had been moderately corroded, the surfaces being covered with a heavy, dark reddish-brown patina.

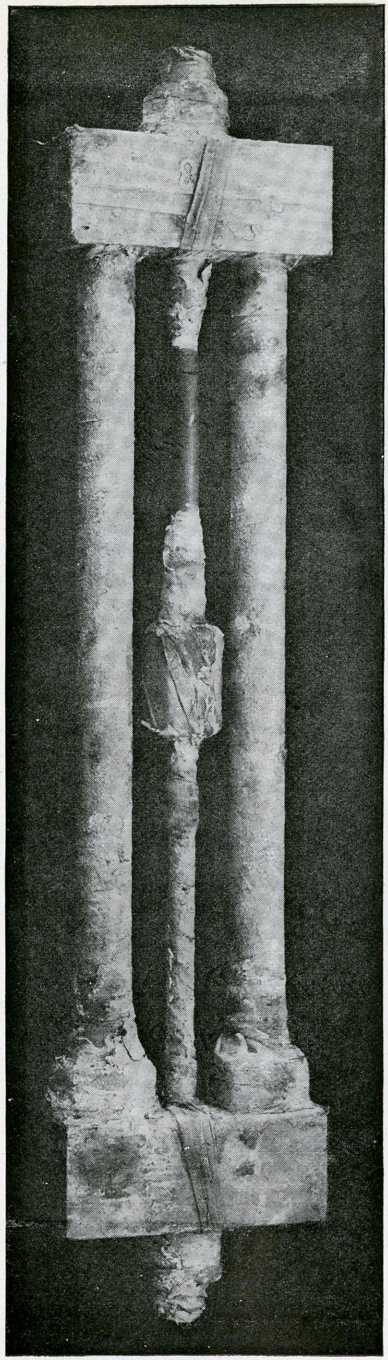

FIG. 2.—*Photograph of frame No. 8 with specimen No. M 239-B, fractured after about one year's exposure to corrosion under a tensile stress of approximately 43 000 pounds per square inch*

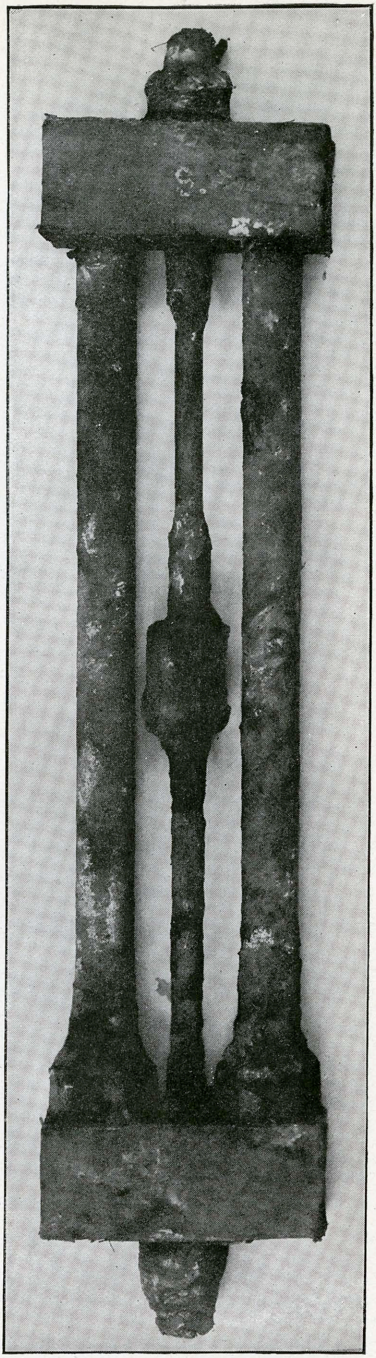

FIG. 3.—*Photograph of frame No. 9 with specimen No. M 239-C after two years' exposure to corrosion under a tensile stress of about 45 000 pounds per square inch*

TABLE 3.—Stresses and Extensions in Brass Specimens as Measured During Loading and Unloading at Different Times During the Test

Frame	Specimen	First loading Dec. 6, 1916			Regaging Dec. 15, 1916			First unloading Mar. 13, 1917			Second loading Mar. 15, 1917			Second unloading Jan. 3, 1919		
		Stress in brass specimen [a]	Stress in brass specimen [b]	Extension of brass specimen [c]	Stress in brass specimen [a]	Stress in brass specimen [b]	Extension of brass specimen [c]	Stress in brass specimen [a]	Stress in brass specimen [b]	Extension of brass specimen [c]	Stress in brass specimen [a]	Stress in brass specimen [b]	Extension of brass specimen [c]	Stress in brass specimen [a]	Stress in brass specimen [b]	Extension of brass specimen [c]
		Lbs./in.^{2}	Lbs./in.^{2}	10^{-3}in.	Lbs./in.^{2}	Lbs./in.^{2}	10^{-3}in.	Lbs./in.^{2}	Lbs./in.^{2}	10^{-3}in.	Lbs./in.^{2}	Lbs./in.^{2}	10^{-3}in.	Lbs./in.^{2}	Lbs./in.^{2}	10^{-3}in.
1	M237–A	15 000	16 300	5.1	....	....	....	17 800	17 600	5.5	14 500	16 300	5.1	14 500	13 100	4.1
2	M237–C	24 600	31 000	9.7	25 000	30 400	9.5	28 000	28 800	9.0	24 500	25 600	8.0	21 800	21 700	6.8
3	M237–D	31 000	41 000	12.8	28 900	42 000	13.1	32 300	34 900	10.9	30 200	32 000	10.0	22 400	23 600	7.4
4	M238–A	19 500	19 500	6.1	....	....	....	20 400	21 000	6.6	19 600	18 900	5.9	18 400	18 200	5.7
5	M238–C	35 000	47 700	14.9	34 800	48 300	15.1	38 400	39 600	12.4	35 300	34 000	10.6	33 400	33 700	10.2
6	M238–D	39 000	56 000	17.5	39 700	57 000	17.8	40 500	43 200	13.5	40 600	39 400	12.3	([d])	([d])	([d])
7	M239–A	25 000	25 300	7.9	25 300	25 600	8.0	27 000	28 200	8.8	24 500	23 300	7.3	21 600	21 100	6.6
8	M239–B	43 600	44 500	13.9	....	....	....	43 800	44 400	13.9	42 600	41 400	12.3	([d])	([d])	([d])
9	M239–C	48 600	51 200	16.0	47 200	52 800	16.5	48 500	49 600	15.5	46 500	45 100	12.9	45 100	44 100	13.8
10	M237–B	30 300	39 400	12.3	29 800	38 700	12.1	....	....	....	....	....	....	39 700	38 100	11.9
11	M238–B	40 200	49 200	15.4	39 900	49 600	15.5	....	....	....	....	....	....	43 000	43 200	13.5
12	M239–D	46 000	49 200	15.4	47 200	49 000	15.3	....	....	....	....	....	....	51 600	50 800	15.9

a This stress calculated from average of strain-gage readings on steel comparison bar.
b This stress calculated from average of strain-gage readings on brass specimen.
c This is expressed directly in 0.001 inch in 5 inches (the gage length was 5 inches).
d Broken.

Specimen No. 238–D, in frame 6, was fractured. No other fractures or cracks were noticed in any of the specimens. Photograph, Fig. 3 shows the appearance of frame No. 9 as it was found on December 30.

The stresses in some of the frames were found to have been slightly reduced during the last exposure period. It is suspected that upon removing the frames from the tank they were dropped or otherwise roughly handled, thus occasioning the loosening of the nuts.

In Table 3 will be found the values of the stress applied to the different brass specimens as measured at each loading and unloading. The first value in each case is the value measured on the steel bar. In the third column is the value of the extension produced in the brass bar, and in the second column of each group the value of the stress in the brass bar, calculated from its own extension (using 16 000 000 pounds per square inch as the modulus).

It will be noticed that the values of the stress calculated from the extensions of the steel bar agree well with those calculated from the extensions of the brass bar, except on the first loading. The brass specimens in frames 2, 3, 5, 6, 10, and 11 evidently yielded slightly and took a permanent set upon their first loading; the stress values of the second column have in this case, therefore, no meaning.

V. CONCLUSIONS

In considering the results of these tests it must be emphasized that the period of exposure—two years—during which the bars have been observed is relatively short in comparison with the periods for which such materials may actually be used in service. The test bars used were given a low temperature anneal, also, in order to relieve the initial stresses, and consequently their behavior may differ during test from that of bars in which these stresses still remain. It is quite apparent, therefore, that any conclusions to be derived from these results must be regarded as quite restricted in their definite application and as more or less tentative in their more general aspects.

Within the period of exposure of two years no specimen of the wrought manganese bronze fractured under a stress below its proportional limit, and four specimens—Nos. M237–C, M237–D, M238–C, and M239–C—did not fracture nor crack under a stress which caused slight yielding and permanent set when first applied.

Fracture or cracking did not occur in any bars stressed to values below 35 000 pounds per square inch. This value does not represent the highest value of the tensile stress withstood during the period of test; specimen M239–C in frame 9 was still quite sound at the end of two years while under a stress of from 45 000 to 48 000 pounds per square inch. Its behavior is considered somewhat anomalous, however, since specimen M239–B of the same temper fractured within about 18 months under a stress of only 41 000 to 45 000 pounds per square inch. It is predicted that the former specimen will eventually fracture under the higher stress.

One specimen with a proportional limit of 35 000 pounds per square inch fractured under a tensile stress of approximately 40 000 pounds per square inch, and another with a proportional limit of 42 500 pounds per square inch under a stress of approximately 43 000 pounds per square inch.

None of the bars in frames 10, 11, and 12, which were protected against corrosion, were fractured at the end of the two years.

The results of these tests seem to be partially, at least, in conformity with the conclusions reached by Jonson from his work using ammonium hydroxide as a corroding medium. His conclusion was that brass or bronze might not be subjected to corrosion (in ammonium hydroxide) while under a tensile stress greater than 20 000 pounds per square inch or greater than 5000 pounds per square inch above the yield point, without danger of failure. The authors' tests indicate that the proportional limit is to be regarded as the maximum safe stress for bronze of harder tempers, but that it is not certain this limit may not be slightly exceeded in materials which are soft; that is, free from work hardness.

Only further exposure tests, which are now proceeding, will decide this point. It is from the practical standpoint very desirable to know whether it is permissible to tighten a bolt of brass or bronze until it yields slightly or whether rigid care must be exercised that the load applied in tightening is at no time above the yield point.

WASHINGTON, February 27, 1919.

PRICE 5 CENTS

SOLD ONLY BY

THE SUPERINTENDENT OF DOCUMENTS,

GOVERNMENT PRINTING OFFICE,

WASHINGTON, D. C.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1919