U. S. DEPARTMENT OF COMMERCE

BUILDING MATERIALS AND STRUCTURES

REPORT BMS58

Strength of Soft-Soldered Joints in Copper Tubing

by

ARTHUR R. MAUPIN
and WILLIAM H. SWANGER

NATIONAL
BUREAU OF STANDARDS

The program of research on building materials and structures, carried on by the National Bureau of Standards, was undertaken with the assistance of the Central Housing Committee, an informal organization of governmental agencies concerned with housing construction and finance, which is cooperating in the investigations through a committee of principal technicians.

CENTRAL HOUSING COMMITTEE ON RESEARCH, DESIGN, AND CONSTRUCTION

NATIONAL BUREAU OF STANDARDS STAFF COMMITTEE ON ADMINISTRATION AND COORDINATION

The Forest Products Laboratory of the Forest Service is cooperating with both committees on investigations of wood constructions.

[For list of BMS publications and directions for purchasing, see cover page III]

UNITED STATES DEPARTMENT OF COMMERCE · Harry L. Hopkins, Secretary

NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS *and* STRUCTURES

REPORT BMS58

Strength of Soft-Soldered Joints in Copper Tubing

by

ARTHUR R. MAUPIN *and* WILLIAM H. SWANGER

ISSUED SEPTEMBER 20, 1940

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

UNITED STATES GOVERNMENT PRINTING OFFICE · WASHINGTON · 1940

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, WASHINGTON, D. C. · PRICE 10 CENTS

Foreword

This paper gives the results of an investigation of the strength of sleeve joints in copper water tubing with wrought-copper and cast-brass couplings soldered with (50–50) tin-lead and (95–5) tin-antimony alloys. The increasing use of thin-walled copper tubing with soft-soldered sleeve joints in domestic plumbing installations and the need for definite information on temperature limitations and the effects of long-time loading on the strength of such joints prompted the investigation, begun in 1936 in cooperation with the Federal Housing Administration. Since 1937 the investigation has been continued on the Research Associate Plan, under the sponsorship of the Copper and Brass Research Association and Committee A40, of the American Standards Association.

In the proposed American Standard for Soldered-Joint Fittings, the pressure ratings were based upon the results of the strength tests described in this paper. Results of similar tests on joints made with other less commonly used soft solders will be given in another paper.

Lyman J. Briggs, *Director.*

Strength of Soft-Soldered Joints in Copper Tubing

by ARTHUR R. MAUPIN *and* WILLIAM H. SWANGER

CONTENTS

	Page
Foreword	II
I. Introduction	1
II. Previous investigations	2
III. Scope of investigation	3
IV. Materials	3
1. Tubing	3
2. Fittings	4
3. Solders and fluxes	4
V. Short-time tensile tests	4
1. Depth of bore	4
2. Diametral clearance; compositions of solder and of metals soldered	5
(a) Test procedure	5
(b) Discussion of results	6
3. Tests at 0° to 350° F on joints made with (50–50) tin-lead and with (95–5) tin-antimony solders	9
VI. Joints made with (50–50) tin-lead solder	9
1. Long-time tests at room temperature (about 85° F)	10
2. Long-time tests at 85° F on joints in 3-inch tubing	12
VI. Joints made with (50-50) tin-lead solder—Continued.	
3. Long-time tests at 123°, 173°, 218°, and 250° F	12
VII. Maximum shear-stress—temperature relations for joints made with (50–50) tin-lead solder	18
VIII. Maximum internal-pressure—temperature curves for joints in copper tubing made with (50–50) tin-lead solder	19
IX. Joints made with (95–5) tin-antimony solder	20
1. Long-time tests at room temperature (about 85° F)	20
2. Long-time tests at 250° and 325° F	21
X. Maximum shear-stress—temperature relations for joints made with (95–5) tin-antimony solder	22
XI. Fluctuating tensile load tests on joints made with (50–50) tin-lead solder	22
XII. Summary	23
XIII. Selected references	25

ABSTRACT

An extended investigation was made of the strength, under tensile loading, of sleeve joints in copper tubing, with wrought-copper and cast-brass couplings, soldered with (50–50) tin-lead and (95–5) tin-antimony alloys. In short-time tests (speed of movable head 0.06 inch per minute) the strength of the joints was substantially equal to that of the tubing or fittings. The strength varied directly with the depth of insertion of the tubing into the fitting, and was greater at diametral clearances of 0.004 to 0.010 inch between tubing and fitting than at greater clearances. The strengths were higher at 0°F than at 85° F and decreased rapidly as the temperature was further increased.

In long-time tests (10,000 hours or more) under constant tensile loads, the strength of joints soldered with tin-lead was about one-eighteenth of that obtained in short-time tests, from 85° to 250° F; joints soldered with tin-antimony had from one-fifth to one-seventh of the short-time strength, depending upon the temperature. At 250° F and upward, diffusion of copper from the tubing into the solder films, in joints made with tin or tin-alloy solders, may weaken or destroy the metallic bond between the solder and tubing.

Results of pulsating tensile-load tests, limited to the joints soldered with (50–50) tin-lead, indicated that the strength under repeated loading was not less than under steady loading.

I. INTRODUCTION

For many years the most commonly used materials for water pipes in buildings were iron and steel, galvanized or uncoated. Copper and brass pipes with threaded fittings were widely used in installations where maximum dependability and freedom from interruptions in service because of corrosion difficulties were desired. Because of the necessity for threading the pipe, the wall thicknesses were the same as those of iron and steel pipes of corresponding sizes. The greater cost of the metals made brass and copper piping considerably more expensive than iron and steel piping.

The excellent resistance of copper to corrosion damage by most municipal water supplies made the heavy wall thickness of iron-pipe-size copper pipe superfluous, and the availability of thin-walled seamless-drawn copper tubing provided a piping material little more expensive per foot of length than iron and steel pipe of equal capacity. The thin-walled tubing could not be threaded to fit ordinary threaded pipe fittings, and various types of compression fittings were devised for joining the tubing. These fittings were expensive and bulky, and difficult to install properly. Thin-walled copper tubing was not widely used for domestic plumbing in this country until the introduction, about 1930, of the sleeve-type fittings for soldered joints. Since that time, the use of thin-walled copper tubing for water piping has increased greatly.

Because of the lack of service records over a sufficiently long time, the strength and permanence of soft-soldered joints in copper tubing were subject to question, and there was need for definite information on their strength under conditions occurring in service.

In 1936 the National Bureau of Standards began a study of the strength of soft-soldered joints in copper tubing, in cooperation with the Federal Housing Administration. Since 1937 this study has been continued under the Research Associate Plan with sponsorship of the Copper and Brass Research Association and Committee A40 of the American Standards Association.

II. PREVIOUS INVESTIGATIONS

Papers giving technical information on the strength of solders and soldered joints are listed in section XIII. Hereafter references to these papers are indicated by numbers in brackets.

General information on soft solders, their compositions, properties, and methods of application, were described by Hiers [1],[1] Nightingale [2], and Macnaughtan, Hedges, and Lewis [3].

Coffman and Parr [7], Dean and Wilson [8], Eyles [9], and Barber [10] discussed fluxes for use with soft solders and theories on the action of such fluxes.

The bonding action between soft solders and the metals joined by soldering was discussed by Daniels and Macnaughtan [6] and by Chadwick [12].

A series of articles by Hook [5] described methods for soldering copper and copper alloys, including sleeve joints in copper tubing.

Gonser and Heath [4] determined physical and mechanical properties of tin-lead solders of different degrees of purity and compared the strengths of lap joints in brass strip, made with the solders they investigated. The strengths under prolonged loading at room temperature of tin and tin-lead solders, and of joints in various metals soldered with tin and tin alloys, were investigated by Freeman and Quick [11].

A number of papers have been published on the rapid decrease in strength of tin, lead, and their alloys, as the temperature is increased above ordinary room temperatures. One of the earliest, dealing with soft solders, was published in 1919 by Hill and Carpenter [13]. Hanson and Sandford [14] investigated the creep properties of tin and tin alloys; McKeown [15] studied the creep of lead and lead alloys. The creep of soft solders and of soldered joints was studied by Baker [16].

In general, the results of these investigations showed that tin, lead, and tin-lead solder alloys elongated appreciably when subjected at room temperature to prolonged tensile loading at stresses much lower than those required to produce fracture in an ordinary tensile test, and further, that the rate of elongation increased rapidly as the temperature was increased. Similar effects of increased temperature, and time under load, were observed on soft-soldered joints, but the strength of the joints could not be determined by tests on the solder alloys themselves.

Very few systematic investigations had been made on the strength of soft- or hard-soldered joints in copper tubing. Noyes [17], of the United States Navy Department, studied the behavior of such joints under different loading conditions, and temperatures up to 400° F. However, quantitative data were lacking on the effects of these variables on the strength of soft-soldered joints in thin-walled copper tubing, under service conditions encountered in domestic plumbing. Available information indicated that joints made with hard solders (brazing alloys) maintained adequate strength to tem-

[1] Figures in brackets indicate the literature references at the end of this report.

peratures at which the tubing and fittings themselves were seriously weakened.

III. SCOPE OF INVESTIGATION

Before planning the program for this investigation, visits were made to the plants of manufacturers of tubing and fittings, and the proposed program was discussed with their technical staffs. In particular, their recommendations were obtained on the methods of making the joints. Observations were made of the types of tubing and fittings, and methods of making the joints, in the plumbing installations of many houses and apartments in and near Washington.

It was decided to confine the study to copper tubing and wrought-copper or cast-brass fittings which were commercially available, and to joints in straight couplings made by the methods which presumably were followed by the plumbers.

The most important factors affecting the strength and reliability of soldered joints in copper tubing in the variety of service conditions encountered in domestic plumbing were considered to be the following:

1. Depth of bore in the fitting, that is, the length of overlap between fitting and tubing, which, in a properly made joint, is completely filled with the film of solder.
2. Diametral clearance between tubing and fitting.
3. Possible difference in strength of joints with cast-brass and with wrought-copper fittings.
4. Effect of temperatures in the range 85° to 250° F on the strength of soft-soldered joints made with different diametral clearances and solders, under different tensile loads maintained constant over long periods.
5. Effects of corrosion.
6. Effect of low temperature (to 0° F).
7. Effect of vibratory stresses.

All the above factors are equally pertinent to hard-soldered joints, except that the elevated temperature effects would be observed at higher temperatures than with soft-soldered joints. However, as hard solders or brazing alloys are not often used in plumbing installations in ordinary housing construction, it was considered advisable to include in the investigation only soft-soldered joints, and at the outset, joints made with (50–50) tin-lead and (95–5) tin-antimony solders. It also seemed inadvisable to undertake activities directed toward development of new solders, fluxes, or new types of tubing and fittings.

IV. MATERIALS

1. Tubing

It is obvious that for satisfactory soldering of sleeve joints the outside diameters of the tubing and inside diameters of the sleeve fittings must be held to close tolerances in order to accomplish satisfactory soldering. Nationally recognized specifications for thin-walled copper tubing, such as those of the American Society for Testing Materials [2] and the Federal Specifications Executive Committee,[3] have been in force for a number of years and manufacturers of such tubing, for use with soldered fittings, apparently have no difficulty in meeting the rigid requirements for dimensions prescribed in these specifications. Observations on tubing and fittings from various representative sources have shown that they are satisfactorily interchangeable.

The type designations, K, L, and M, of these specifications have become "standard" designations for thin-walled copper water tubing in the industry. For equal nominal sizes the outside diameters of all types are the same. In the smaller sizes used in household plumbing, the wall thickness of type M (the thinnest) is approximately 70 percent of that of type L, which, in turn, is about 70 percent of that of type K (the thickest). The wall thickness of "standard" iron pipe is about twice that of type K, 2½ to 3 times that of type L, and nearly 4 times that of type M.

Types K and L are available in the annealed and in the hard-drawn condition as well as in intermediate tempers, with tensile strength ranging from about 30,000 pounds per square inch for the annealed tubing to about 50,000 pounds per square inch for the hard drawn

[2] Standard Specifications for Copper Water Tube, ASTM Designation: B88–39. Am. Soc. Testing Materials, Standards, pt. 1, Metals, p. 640 (1939).

[3] Federal Specification WW–T–799, Tubing; Copper, Seamless (for use with soldered or flared fittings). Obtainable from Superintendent of Documents, Washington, D. C. Price 5 cents.

tubing. Type M is available generally only in the hard-drawn condition.

2. Fittings

Both cast and wrought fittings for soft-soldered joints in thin-walled copper tubing are available commercially. Cast fittings are made generally from "red brass" (85 percent of copper, 5 percent of tin, 5 percent of zinc, 5 percent of lead); wrought fittings, from copper of the same composition as the tubing. Most of the specimens used in this investigation were made with ¾-inch types K or L tubing and straight couplings of either wrought copper or cast brass.

3. Solders and Fluxes

The joints in thin-walled copper tubing for carrying water are most generally made with soft solders. Tin-lead solders predominate, the familiar "half-and-half," or 50-percent-tin–50-percent-lead alloy, being the composition most frequently used. This alloy flows readily at 420° F, at which temperature hard-drawn copper tubing is not softened by annealing during the time required to solder a joint.

During the past few years the composition 95-percent-tin, 5-percent-antimony has come into the field of soft solders for this type of work. This alloy flows readily at about 465° F, which also is not sufficiently high to soften significantly the hard-drawn tubing when the joints are made.

The alloys, 5 percent tin and 95 percent lead, molten at about 595° F; 39 percent tin, 1 percent antimony, and 60 percent lead, molten at about 430° F; 2.5 and 5 percent silver, remainder lead, molten at about 580° and 670° F, respectively; and 5 percent silver and 95 percent cadmium, molten at about 740° F; may also be included in the class of soft solders.

Joints in the three "standard" types of thin-walled copper tubing can be made with "hard" solders or brazing alloys melting in the range 1,175° to 1,300° F. At these temperatures, however, the hard-drawn tubing is annealed so that the strength of the tubing in the vicinity of the joint is practically that of annealed tubing. The hard solders are used for installations in which the tubing may be subjected, during service, to temperatures at which soft solders would not be reliable.

Zinc chloride or mixtures of zinc and ammonium chlorides are used almost exclusively as fluxes for soft-soldered joints. These fluxes are acid in reaction, but unless needlessly excessive amounts have been used, no damage to the joint by corrosion is to be feared. Apparently the most satisfactory form in which to use the flux for making sleeve-type joints in tubing is to have the fluxing material incorporated with mineral grease into a paste. Such preparations are available commercially.

With the hard solders, a flux that is not decomposed at the soldering temperature must be used. Borax or mixtures of borax and boric acid are satisfactory.

Soft-soldered joints in copper tubing are made satisfactorily with gasoline or air-acetylene torches; hard-soldered joints require the use of an oxy-gas or oxy-acetylene torch, preferably the latter.

No difficulties were encountered in obtaining properly soldered joints with diametral clearances of about 0.004 inch, in which the solder was uniformly and completely spread throughout the space designed for it. Many joints were sectioned to ascertain this fact. In the tests involving strengths at different clearances up to 0.060 inch, special means were used for filling the joints with diametral clearances more than 0.008 inch.

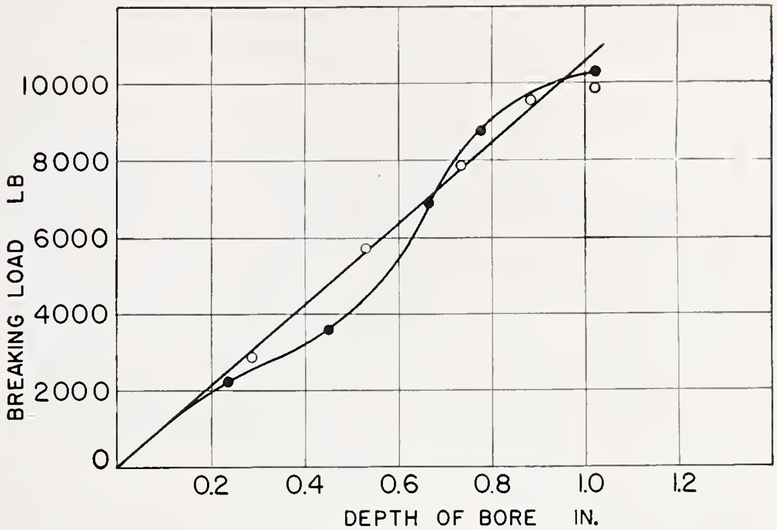
V. SHORT-TIME TENSILE TESTS

1. Depth of Bore

Joints with depth of bore ranging from ¼ to 1 inch, were made with (50–50) tin-lead solder, ¾-inch K-hard tubing, and both wrought-copper and cast-brass couplings. The joints were pulled apart in a screw-driven beam-and-poise tensile testing machine having a capacity of 10,000 pounds. Before the loads were applied, the speed of the movable head of the testing machine was adjusted to 0.06 inch per minute of travel under no load. This speed setting was used for all of the short-time tensile tests reported in this paper. The results, plotted in figure 1, showed that the loads to

Figure 1.—*Variation of breaking load with depth of bore; ¾-inch type K tubing soldered with (50–50) tin-lead.*

Wrought-copper couplings, open circles. Cast-brass couplings, solid circles. Diametral clearance, 0.004 inch. Short-time tensile tests. Speed of movable head, 0.06 inch per minute.



rupture the soldered joints increased in an approximately direct proportion to the increase in depth of bore in the fitting, in both types of fitting.

It was observed also that all of the commercial fittings for types K, L, and M tubing are designed to permit the insertion of the tubing for a sufficient depth so that a properly soldered joint, as a rule, is stronger, in a short-time tensile test, than the tubing or the fitting.

2. Diametral Clearance; Compositions of Solder and of Metals Soldered

(*a*) *Test Procedure*

Tensile tests at room temperature, with a speed of 0.06 inch per minute of the movable head of the testing machine, were made on joints having diametral clearances over the range 0.002 to 0.060 inch. Some difficulty was experienced in inserting the tubing into the fittings when the difference between the mean outside diameter of the tubing and the mean inside diameter of the fitting was less than 0.001 inch. A satisfactory joint is generally obtained if the tubing can be inserted into the fitting by hand. When the clearance is greater than 0.008 inch, there is difficulty in filling the joint properly. The tubing and fittings, as furnished commercially, provide a diametral clearance of 0.004 inch, that is, an annular space around the tubing 0.002 inch in width. For diametral clearances ranging from 0.002 to 0.008 inch, capillary action causes both types of solders to flow readily to the extremities of the overlap between tubing and fitting.

Heavy copper pipe and solid rod were used in making the specimens for testing the effect of different clearances, because the thin-walled tubing invariably broke before the joint did.

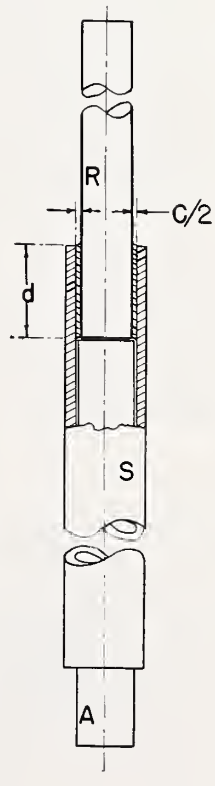


Figure 2.—*Specimen assembly for tensile tests of joints with different diametral clearances, or different depths of bore.*

Solid rod *R* was turned to different diameters to vary clearance, when inserted into sleeve *S*. Thickness of solder film, *C*/2, is half of diametral clearance. Solid rod *A* was used as stop to fix depth of insertion (bore depth) *d*.

Both copper and brass (60 percent of copper, 40 percent of zinc) rods were used for one member of the joined specimens.

A section of the specimen assembly is shown in figure 2. The sleeve, *S*, about 6 inches long, was cut from copper pipe having an inside diameter of 0.628 inch. The diametral clearance, *C*, was varied by turning the solid rod, *R*, to different diameters. Rod *A* was used as a stop to fix the bore depth, *d*, and was withdrawn after the joint was soldered. Precautions were taken to locate the rod centrally within the sleeve, *S*. In several specimens the rod was intentionally placed to one side of the sleeve. The strength of such "off center" joints was approximately the same as for accurately centered joints. Several joints were sectioned longitudinally and were found to have the annular space between the rod and sleeve completely filled with solder.

The sequence of the tests to determine the effect of different clearances with different solders and fittings was as shown in table 1.

(*b*) *Discussion of Results*

It was found that in short-time tensile tests the strength of joints between solid brass rods and copper sleeves, test 1, varied among different specimens of approximately the same diametral clearance, and that the strength of joints increased with increase in clearances from 0.003 to 0.030 inch. For clearances from about 0.030 to 0.060 inch a slight decrease in strength was indicated. The results are plotted on curve 1, figure 3. The strength of the joints in the short-time tensile tests was calculated in terms of shear stress on the soldered area at the maximum tensile load. The soldered area was calculated from the outside diameter of the tubing and the length of tubing inserted into the fitting.

In most of the separated joints more solder was found adhering to the copper sleeve than to the brass rod. It was considered that differences in absorption by the solder of zinc from the brass might have caused the scatter in results in test 1. Consequently, the ends of the separated joints were reheated to melt the adhering solder, which was then wiped off with a rag. The joints were again fluxed and resoldered with new solder. The strength of the resoldered joints was definitely higher, having gained nearly 30 percent at all clearances over that of the joints soldered only once. The results are plotted on curve 2, figure 3. It was noted that, in the joints separated after the second soldering, more of the solder had adhered to the brass rods than was the case after the first soldering.

The separated joints from the second series of tests were again cleaned and made once more with new solder. The results for these joints are plotted on curve 3, figure 3. It was found that for joints with clearances up to about 0.010 inch a further increase in strength was obtained, but that with greater clearances the strength of the joints soldered three times was about the same as that of the joints soldered twice.

It is noteworthy that only after the brass-to-copper joints had been soldered three times was the strength of the joints with small clearances, up to 0.010 inch, greater than that of joints with larger clearances. It is a generally accepted principle, based on numerous observations, that when maximum adherence of solder to basis metal is obtained, the thinner the film of solder the stronger the soldered joint.

The results of the short-time tensile tests on joints between solid copper rods and copper

TABLE 1.—*Sequence of tests at different diametral clearances*

Test No.	Diametral clearance	Joint members	Solder	Remarks
	Inches			
1	0.003 to 0.062	Brass (60-40) rod and copper sleeve	(50-50) tin-lead	
2	0.003 to 0.062	do	do	Resoldered after test 1.
3	0.003 to 0.062	do	do	Resoldered after test 2.
4	0.002 to 0.059	Copper rod and copper sleeve	do	
5	0.002 to 0.059	do	do	Resoldered after test 4.
6	0.002 to 0.059	do	(95-5) tin-antimony	
7	0.002 to 0.059	do	(49-49-2) tin-lead-zinc	
8	0.002 to 0.059	do	(48.68-48.68-2.64) tin-lead-antimony	
9	0.004	do	100 percent lead to 100 percent tin	

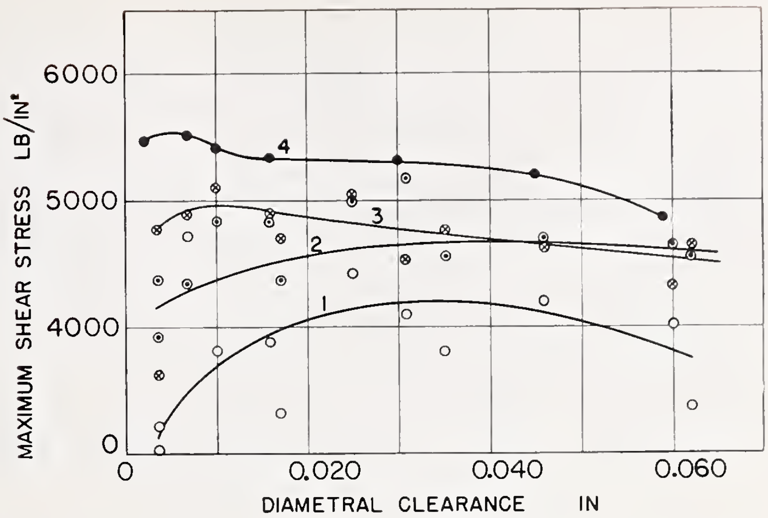


FIGURE 3.—*Strength of soldered joints at different diametral clearances.*

Curves, 1, 2, and 3 for yellow-brass (60 copper, 40 zinc) rods soldered once, twice, and three times, with (50–50) tin-lead, into copper sleeves. Curve 4, copper rod soldered into copper sleeve. Short-time tensile tests. Speed of movable head, 0.06 inch per minute.

sleeves, made with tin-lead solder, were fairly consistent, as indicated by curve 4, figure 3. The strength of these joints was considerably greater than that of the brass-to-copper joints, even when the latter type had been soldered three times. It is to be noted also that the copper-to-copper joints with small clearances, up to 0.010 inch, were stronger than when larger clearances were used.

Resoldering the separated joints from test 4 did not result in a significant change in strength, as is shown by curve 5, figure 4. Curve 4 from figure 3, copper-to-copper joints soldered once, is also plotted in figure 4 for ready comparison with curve 5, copper-to-copper joints soldered twice.

It was observed that in the separated copper-to-copper joints a film of solder had adhered to both the copper rod and to the copper sleeve, and to about the same extent in the joints soldered once as in those soldered twice. Rupture had taken place by shear through the solder. Evidently the adherence of tin-lead solder to copper is stronger than it is to brass.

Results of short-time tensile tests of the copper-to-copper joints, soldered with (95–5) tin-antimony (curve 6, fig. 4) showed that they were stronger, by about 13 percent, at all clearances than similar joints made with tin-lead solder.

A definite indication was obtained that the lower strength of the brass-to-copper joints,

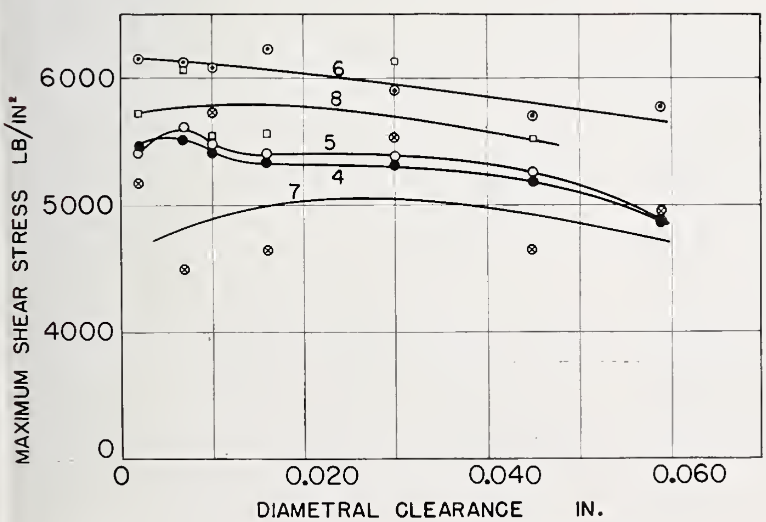


FIGURE 4.—*Strength of soldered joints at different diametral clearances: copper rod and copper sleeve.*

Curves 4 and 5, first and second soldering with (50–50) tin-lead. Curve 6, for (95–5) tin-antimony solder. Curve 7, for (49–49–2) tin-lead-zinc solder. Curve 8, for (48.68–48.68–2.64) tin-lead-antimony solder. Short-time tensile tests. Speed of movable head, 0.06 inch per minute.

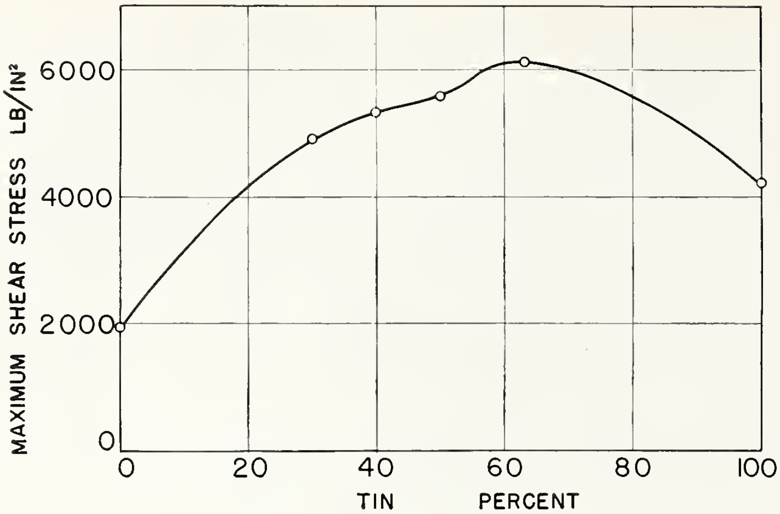


FIGURE 5.—*Strength of joints, copper to copper, soldered with tin, lead, and tin-lead alloys with different tin contents.*

Short-time tensile tests. Speed of movable head, 0.06 inch per minute.

as compared to copper-to-copper joints, was not due solely to differences in adhesion of the solder to the brass and the copper, but partly, at least, to absorption by the solder of zinc from the brass. Joints between copper rods and copper sleeves were soldered with an alloy containing equal parts of lead and tin and 2 percent of zinc. The results, plotted on curve 7, figure 4, showed that the addition of zinc to ordinary (50–50) tin-lead solder caused a lowering of the strength in copper-to-copper joints. These experiments indicated that zinc should be kept out of tin-lead solders insofar as possible.

Copper-to-copper joints made with (50–50) tin-lead solder to which has been added 2.63 percent of antimony were not so strong as the joints soldered with the (95–5) tin-antimony, but were stronger than those soldered with (50–50) tin-lead alloy. The results are plotted on curve 8, figure 4. These tests indicated that the addition of antimony to (50–50) tin-lead solder results in increased strength in the soldered joints. Further tests showed that joints in the larger sizes did not fill as easily with solders containing antimony as did those made with (50–50) tin-lead solder.

It is evident from figures 3 and 4 that there was no significant variation in the strength of the joint between copper rod and copper sleeves for different diametral clearances up to 0.010 inch.

Short-time tensile tests were made on a number of copper-to-copper joints soldered with

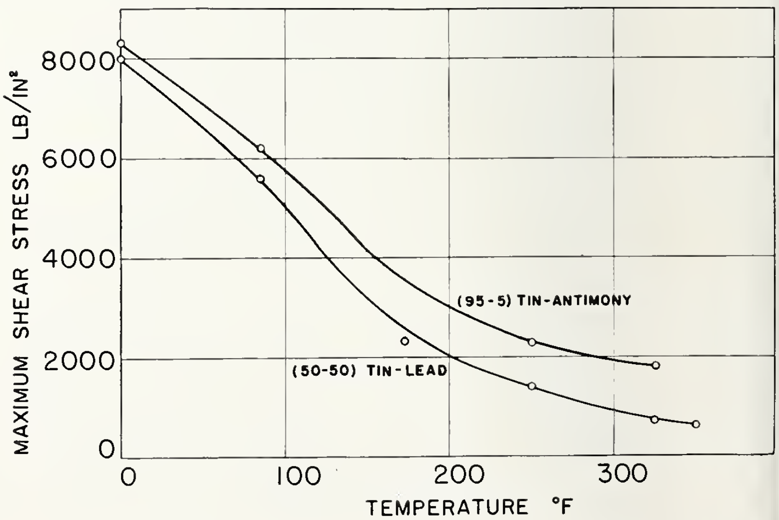


FIGURE 6.—*Strength of copper-to-copper joints, soldered with tin-lead and tin-antimony, in short-time tensile tests at 0° to 350° F.*

Speed of movable head, 0.06 inch per minute.

pure tin, pure lead, and alloys of various proportions of tin and lead, including the eutectic mixture of 63 percent of tin and 37 percent of lead. The results plotted in figure 5 showed that the joints soldered with the eutectic mixture were stronger than those soldered with other tin-lead alloys. It is more difficult to make sleeve joints with the eutectic mixture, melting at a definite temperature, than it is to use the (50–50) tin-lead solder, having a melting range of about 55° F.

3. Tests at 0° to 350° F on Joints Made With (50–50) Tin-Lead and With (95–5) Tin-Antimony Solders

Figure 6 shows the results obtained on a series of short-time tensile tests (speed of movable head 0.06 inch per minute) at 0°, 85°, 175°, 250°, 325°, and 350° F on joints made with (50–50) tin-lead solder; and at 0°, 85°, 250°, and 325° F on joints made with (95–5) tin-antimony solder. For the tests at 0° and 85° F, the joints were made with ¾-inch solid copper rod inserted into couplings made from ¾-inch iron-pipe-size copper pipe, because the strength of "standard" tubing and couplings was not adequate to support the loads necessary to rupture the solder films at these temperatures. The maximum shear stresses for tests at 85° F on joints made with ¾-inch type K tubing and commercial wrought-copper couplings (results not plotted in fig. 6) were somewhat lower than those obtained from the copper rod and pipe combinations. The tubing and couplings showed considerable distortion after fracture of the joints, which apparently caused the lower maximum shear stresses. Type L tubing and wrought-copper couplings were adequate for the tests at 175° F and higher. The depth of bore in the couplings was ⅞ inch, and the diametrical clearance for all of the joints was 0.004 ± 0.0006 inch.

For the elevated-temperature tests the specimens were heated by an electric furnace surrounding the specimen. The temperature of the specimen was measured with thermocouples peened into the tubing at each end of the coupling. The tests at 0° F were made with the specimens immersed in a bath consisting of equal volumes of ethylene glycol and water cooled with solid carbon dioxide.

The markedly higher strength of the joints of 0° F as compared to that at 85° F and the rapid decrease in strength as the temperature was increased above 85° F are in qualitative agreement with the results that would be expected from tensile tests of the solder alloys themselves, although not in quantitative agreement at any of the temperatures. It is noteworthy also that the joints made with tin-antimony solder did not lose strength as rapidly as did those made with tin-lead solder, as the temperature was increased above 85° F.

VI. JOINTS MADE WITH (50–50) TIN-LEAD SOLDER

Numerous tests, the results of which are not given in detail in this paper, showed that the strength of joints made with tin-lead or tin-antimony solders, in short-time tensile tests made at room temperature, was practically equal to that of the hard-drawn type K tubing, and generally greater than that of hard-drawn types L and M tubing, and of all three types in the annealed condition. Creep at room temperatures shown by the soft-solder alloys under sustained tensile loads was encountered also in joints soldered with these alloys. Sleeve joints in copper tubing made with tin-lead may fail by shear in the solder film in about 40 days, under sustained tensile loads only one-tenth as great as the loads necessary to rupture the joints in short-time tensile tests.

The rapid increase in creep rates of the soft-solder alloys with increase in temperature [16] is also a factor in determining the strength of soft-soldered joints in copper tubing when such tubing is subjected to temperatures above room temperature. Time and temperature are therefore two interdependent variables affecting the loads necessary to cause creep and rupture in soft-soldered joints. The conditions in the solder films in sleeve-type joints in tubing are such that these loads cannot be ascertained from the known or determined creep rates of the solder alloys themselves.

As a basis for limitations that might be imposed on installations of copper tubing assembled with sleeve-type soldered joints, it is important to know the maximum stresses that can be imposed continuously on the joints without causing slip, extension, or rupture, in the solder films, during the normal life expectancy of the installations. In addition to information on the strength at atmospheric temperatures, it is necessary to know the rate at which the strength decreases as the temperature is increased.

By means of a simple lever-system loading device, figure 7, specimens with soldered joints were subjected to constant tensile loads for extended periods at room and at elevated temperatures. Four test racks were constructed, each accommodating nine specimens loaded independently. A load as high as 4,000 pounds could be applied to each specimen. Calibration with proving rings showed that the loads applied to the specimens were within one-half percent of the loads calculated from the lever ratio and weights on the weight pan.

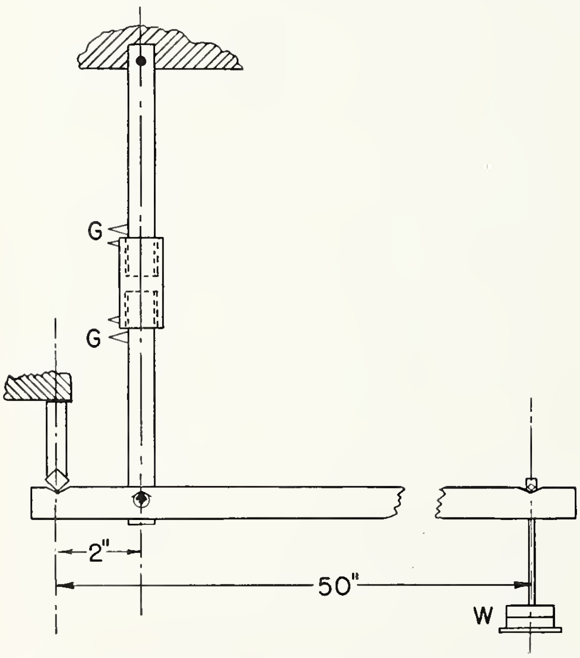


Figure 7.—*Sketch of loading device for maintaining constant tensile load on soldered joints in copper tubing.*

Gage marks, for measuring extensions in upper and lower joints in coupling, at *G*.

1. Long-Time Tests at Room Temperature (about 85° F)

The specimens for long-time tests at room temperature consisted of lengths of ¾-inch type L hard-drawn tubing connected in series with four straight couplings, two of wrought copper and two of cast brass. The diametral clearance at the upper joint in each coupling was 0.008 inch; that at the lower joint on each coupling was 0.004 inch. These clearances had a tolerance of ±0.0006 inch. The tubing (0.875 inch O. D.) was inserted into the coupling to a depth of 0.87, 0.95, or 1.01 inch, ±0.01 inch. The soldered areas were calculated from these dimensions. As a tensile load on the specimen produced a stress predominantly in shear on the solder film, the shear stress calculated from the load and soldered area provided a common basis for evaluating the strengths of the joints having different dimensions.

The annular space between the tubing and coupling was filled with solder by the conventional procedures recommended for installations in buildings. Sectioning of extra joints made for the purpose indicated that the annular spaces on the specimens used for the long-time tests were completely filled. This was verified when the joints were sectioned after the tests had been completed.

Suitable gage marks were attached firmly to the tubing and coupling at each joint. The extension of the joint resulting from slip or shear in the solder film was indicated by the increased distance between the gage marks, which was originally in the range 0.02 to 0.04 inch. These distances were measured with a traveling microscope to a precision of 0.0001 inch. The accuracy of the measuring instrument was checked with a standard scale and was well within the precision of measurement. It was considered that total extensions of 0.001 inch or less, in the joints, were not significant. In addition to the obvious failures in the joints under sustained tensile loads, it was considered that joints which were not visibly ruptured would fail eventually if there was an increasing curvature away from the line of zero extension, in a curve of extensions plotted against time. When one of the eight joints in a specimen had failed, a pin inserted in a hole drilled through the overlapping coupling and tube keyed the failed joint and the remaining joints in the specimen were retained under the original load.

Loads ranging from those causing no measureable extensions during 10,000 hours to those

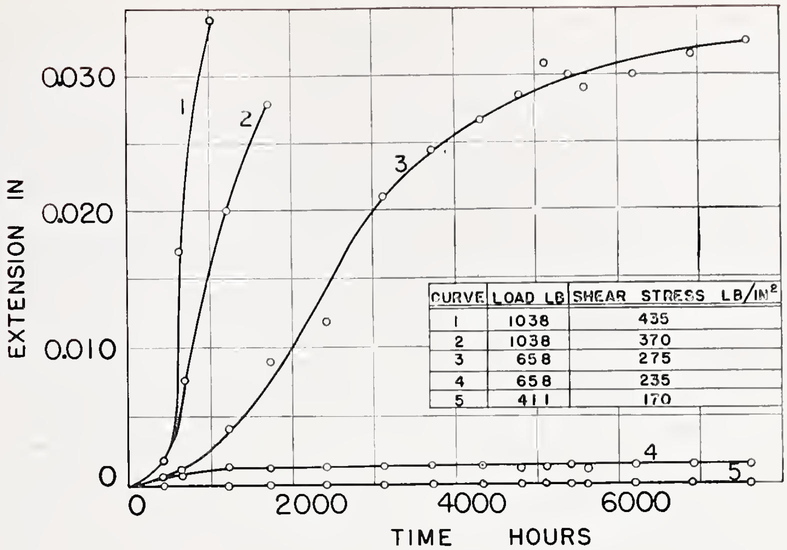


Figure 8.—*Extension-time curves for joints in type L tubing with copper couplings; soldered with (50–50) tin-lead.*

Diametral clearance, 0.004 inch. Tests at room temperature (85° F).

causing failure of the joints in a few hundred hours were applied to a sufficient number of specimens, each with eight joints, to obtain a valid estimate of the maximum shear stress that could be sustained by the joint under continued tensile load.

Observed extensions plotted against time, for representative joints in copper couplings made with tin-lead solder, are given in figure 8. Similar data for joints in cast brass couplings are given in figure 9. Results are given only for joints with 0.004-inch diametral clearance. The extensions observed on the upper joints of each coupling, with 0.008-inch diametral clearance, were in general greater than on the joints with 0.004-inch clearance. The latter clearance is the average obtained within the present tolerances for dimensions of tubing in the nationally recognized standards [4] and in a proposed standard [5] for cast and wrought sleeve-type fittings. The clearance of 0.008 inch was obtained by cutting down the outside of the tubing or enlarging the bore of the coupling. As the maximum permissible stress estimated for the joints with 0.008-inch clearance was not significantly less than that for the joints with

[4] See footnotes 2 and 3.

[5] Proposed American Standard, "Soldered-Joint Fittings."

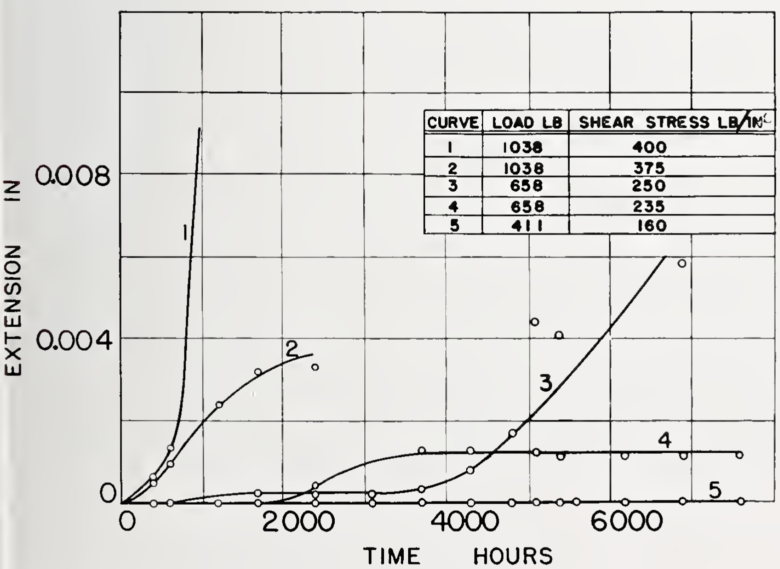


Figure 9.—*Extension-time curves for joints in type L tubing with cast-brass (85 copper, 5 tin, 5 zinc, 5 lead) couplings; soldered with (50–50) tin-lead.*

Diametral clearance, 0.004 inch. Tests at room temperature (85° F).

0.004-inch clearance, it was not considered necessary to present detailed data on the joints with the larger diametral clearance.

It is evident from an inspection of the curves, figures 8 and 9, that the joints in the copper couplings would eventually fail when subjected continuously to a tensile load causing a shear stress on the soldered area of 275 pounds per square inch or greater. In the joints with the cast-brass couplings, eventual failure was indicated at shear stresses of 250 pounds per square inch or greater. No significant extensions, nor increasing rates of extension, were observed in joints with either type of coupling, at shear stresses of 235 pounds per square inch or less. Although data presented cover a period of 7,500 hours, the tests at the lower stresses were continued to 10,000 hours with no change in the extensions. On the basis of these results it was concluded that 235 pounds per square inch (658-pound tensile load on ¾-inch tubing) was a conservative value of the maximum shear stress on the soldered area that can be maintained for an indefinitely long time at room temperature (85° F) by sleeve-type joints made with (50–50) tin-lead solder. The temperature of the testing laboratory fluctuated about 10° F plus and minus, from the 85° F value indicated as room temperature.

It is noteworthy that the maximum permissible shear stress (235 pounds per square inch) in the tin-lead solder films for joints subjected to continued tensile loading at 85° F is only $\frac{1}{18}$ of the ultimate shear stress in short-time tests of similar joints, and only $\frac{1}{24}$ of the ultimate shear stress in joints between copper rod and heavy-walled copper pipe (fig. 6).

2. Long-Time Tests at 85° F on Joints in 3-inch Tubing

A number of specimens of joints in 3-inch copper tubing, soldered into cast-brass couplings with tin-lead solders, were subjected to sustained tensile loads causing shear stresses on the soldered areas of 235 pounds per square inch to determine whether the larger size would have any significant effect on the strength of the joint.

Joints were made with two types of 3-inch tubing, type K with a wall thickness of 0.109 inch and type O with a wall thickness of 0.049 inch, type O being commonly used in sizes of 3 inch and over.

The outside diameter of both types was 3.125 inches, and the tubing was inserted into the couplings to a depth of 1⅞ inches. The diametral clearance was 0.004 ± 0.001 inch. For a shear stress of 235 pounds per square inch on the soldered film, the tensile stress in the tubing was 4,200 pounds per square inch for type K and 9,100 pounds per square inch for type O. No distortion of the tubing was to be expected at such low tensile stresses.

The tests were continued to approximately 9,000 hours. Several joints in type K tubing and one in the type O tubing failed after 3,000 to 5,000 hours. It was found, after the failure, that the solder had filled only from 60 to 80 percent of the annular space between the tubing and coupling, so that the actual shear stress in the solder films was greater than 235 pounds per square inch. Several other joints which had not failed were found to have more than 90 percent of the annular space filled with solder.

It was concluded that 235 pounds per square inch on the solder film, determined as the maximum allowable shear stress for continued loading at 85° F for joints in the ¾-inch tubing, would apply also to larger tubing, but only when 90 percent or more of the annular space between tubing and couplings was filled with solder.

It was found practically impossible to completely fill the joints on tube sizes of 2 inches and larger, with the ordinary soldering technique, probably because the entire circumference of the tubing and coupling cannot be brought to the proper soldering temperature at the same time. In using the value 235 pounds per square inch as the maximum allowable shear stress on the solder film for continued tensile loading of the joint, a greater allowance for imperfections in soldering should be made for joints in tubing larger than 2 inches than for joints in smaller tubing.

3. Long-Time Tests at 123°, 173°, 218°, and 250° F

To determine the effect of temperatures above 85° F on the long-time strength of joints made with tin-lead solder, tests similar to those described for the room-temperature tests were made at 123°, 173°, 218°, and 250° F. Each specimen contained two joints, one at each end of a straight coupling. Type L, hard-drawn tubing, ¾-inch nominal size, was used with wrought-copper and cast-brass couplings from several sources. The portion of the specimen containing the coupling and its two soldered joints was enclosed in a heating chamber constructed from 2½-inch glass tubing, closed at the top and bottom with asbestos board, as shown in figures 10 and 11. Helically wound heating elements were placed on suitable supports, within the glass chamber. Thermocouples peened into the middle of the couplings were used to indicate the temperatures. There was no significant temperature gradient along the length of the coupling, and the temperatures were constant to within plus or minus 7° F of the test temperatures. The deviations from a constant temperature were considered not to have a significant effect on the results obtained with this type of test. Extensions in the joints were measured with the same measuring microscope used for the room-temperature tests, sighted through the glass walls of the heating chamber. The microscope is shown in position for observing in figure 10. Fine marks made with a razor blade on short wires soldered to the coupling and tube at each joint were used as gage marks.

Figure 10 shows a group of nine specimens mounted in the testing fixtures. Figure 11 is a close-up view of two specimens, with the heating chamber lowered from the coupling of one specimen. The wires containing the gage marks are visible on the latter specimen.

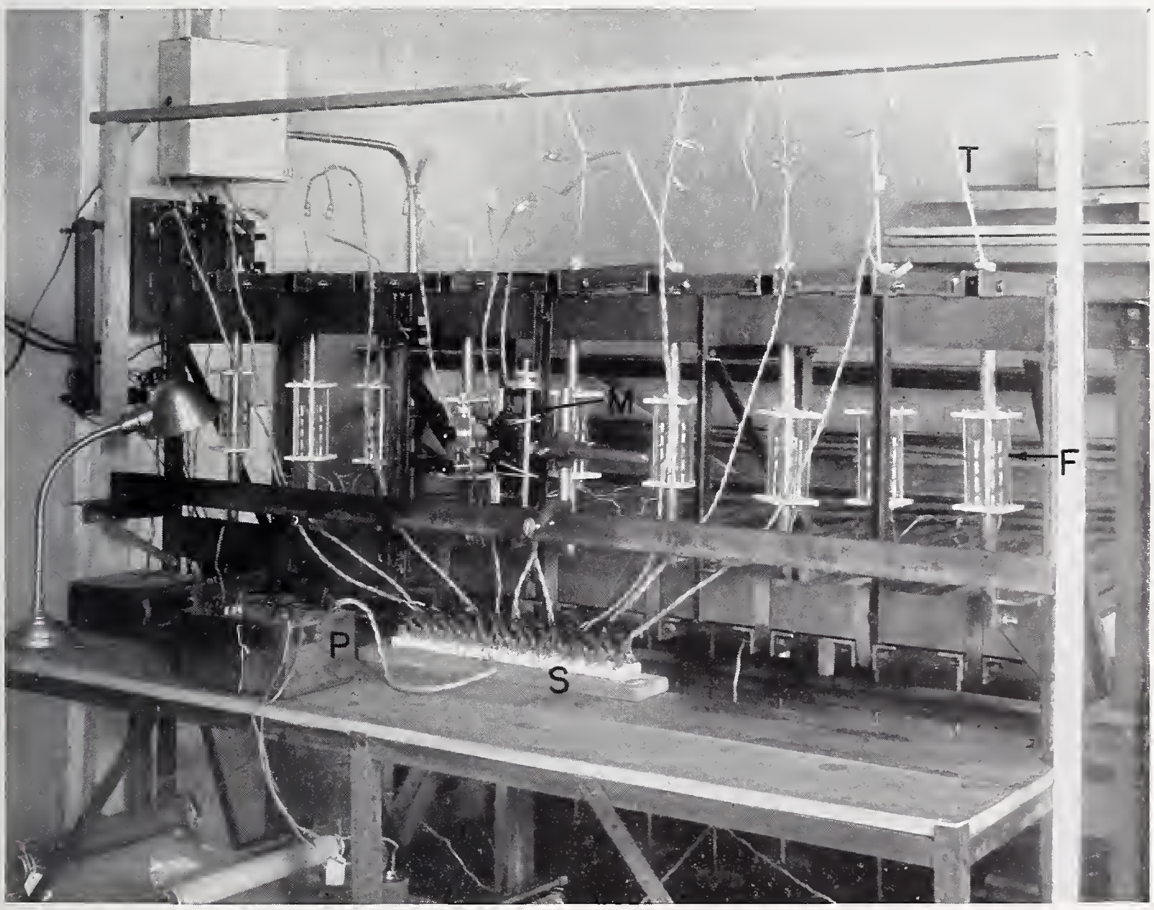


FIGURE 10.—*Specimens of soldered joints mounted in fixtures for elevated-temperature tests at constant tensile loads.*

Glass-walled heating chambers, *F*, enclose couplings. Leads *T* to thermocouple peened into middle of coupling. Potentiometer *P* connected through switches *S* to thermocouple leads. Extensions between gage marks measured with measuring microscope *M*.

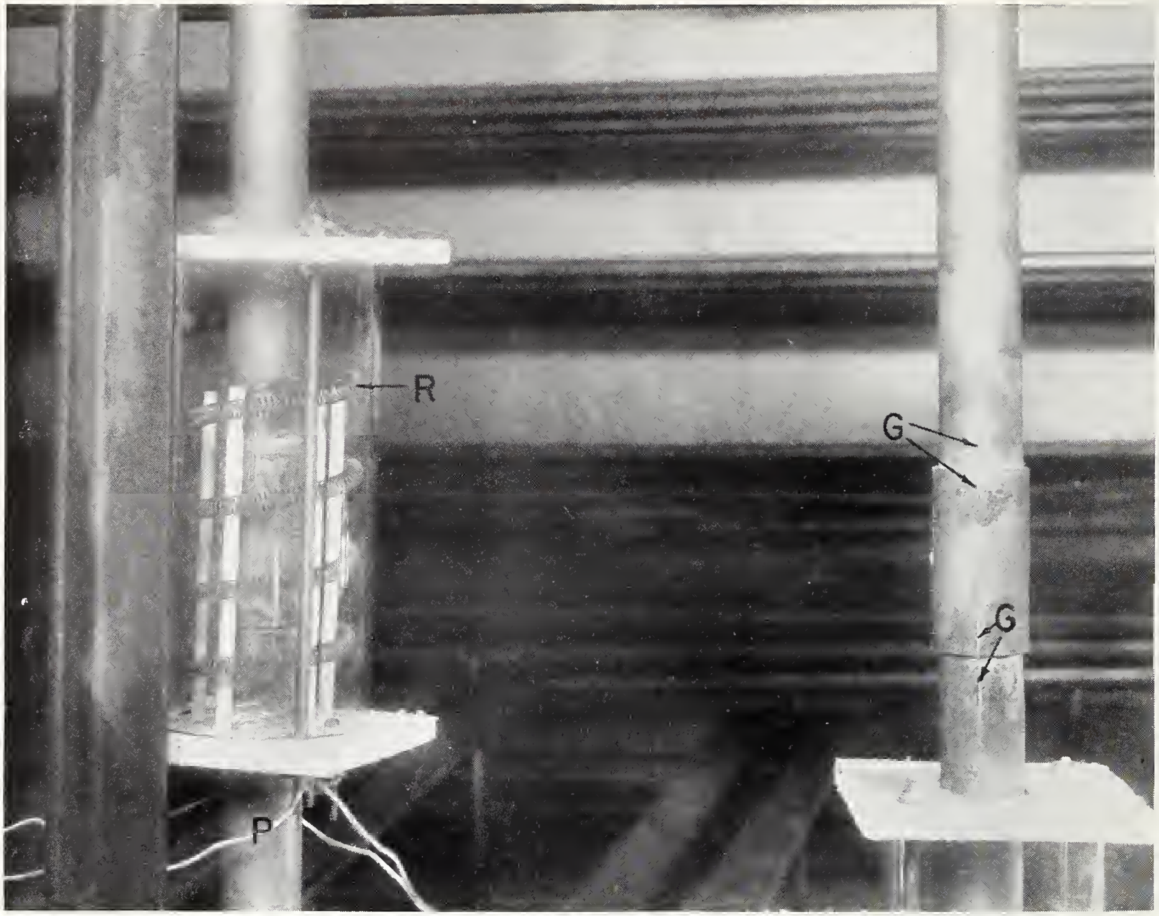


FIGURE 11.—*Close-up view of two specimens.*

Heating chamber lowered from coupling of specimen at right. Gage marks placed on wires *G* soldered to tubing and coupling. Heating element, *R*; power leads, *P*.

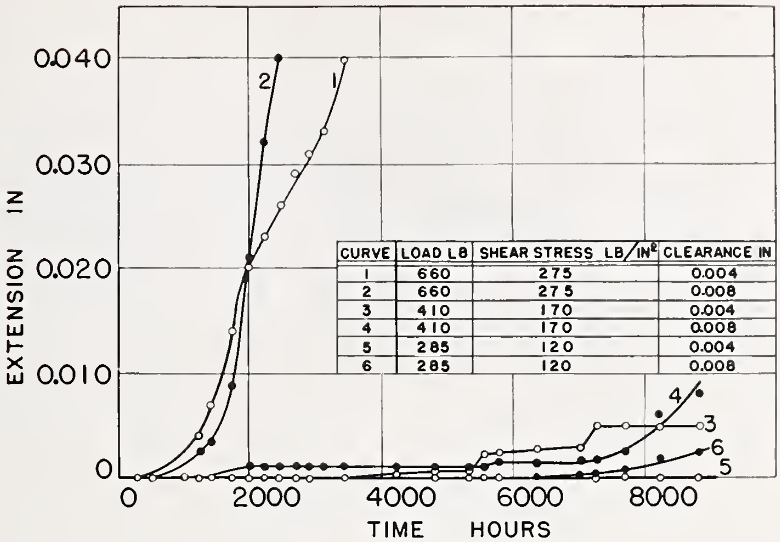
For the tests at 123°, 173°, and 218° F, the tubing was inserted into wrought-copper couplings to a depth of 0.87±0.01 inch. For the upper joint in each coupling the diametral clearance was 0.008 inch; for the lower joint, 0.004 inch. The tolerance on both these dimensions was 0.0006 inch.

Tensile loads of 660, 410, and 285 pounds were applied to specimens maintained at each of the three temperatures 123°, 173°, and 218° F. The shear stresses on the soldered areas corresponding to the three different loads were 275, 170, and 120 pounds per square inch. Observations of extensions in the joints were made daily in the early parts of the tests and at suitable intervals, the length of which depended upon the rates of extension, throughout the duration of the tests. Some of the tests were prolonged to 12,000 hours.

The observed extensions for the three shear stresses are plotted against time in figure 12 for the tests at 123° F, in figure 13 for the tests at 173° F, and in figure 14 for the tests at 218° F. Early failure occurred in the joints held at 173° F at a shear stress (on the soldered area) of 275 pounds per square inch, and the extensions were so large that they could not be plotted in figure 13 on the scale used for this graph. The deviations of the plotted points from a smooth curve, figures 12 to 14, were the result of measuring extensions on only one side of the specimens. The joints undoubtedly did not extend uniformly around the circumference. The deviations from uniform extension were much smaller than the total extensions, indicating eventual failure; and it was concluded that gage marks placed on only one side of the specimen were adequate for the purpose.

Figure 12.—*Extension-time curves for joints in type L tubing with copper couplings; soldered with (50–50) tin-lead.*

Tests at 123° F.



It is evident from an inspection of the curves that the joints with a diametral clearance of 0.008 inch extended at a significantly greater rate than did those with a clearance of 0.004 inch, at each of the loads and temperatures. Furthermore, the joints with 0.008-inch clearance were extending at an increasing rate, indicating eventual failure.

At 123° F, the joints with 0.004-inch clearance and subjected to shear stresses of 120 and 170 pounds per square inch showed no significant extensions in 8,800 hours. In preliminary experiments, similar joints, held at 123° F, were extending at an increasing rate under shear stresses of 208 pounds per square inch. It was concluded, therefore, that 170 pounds per square inch was the maximum allowable shear stress for joints with 0.004-inch clearance held continuously at 123° F. At 173° F the joints loaded to a shear stress of 170 pounds per square inch were extending at a rate indicating eventual failure. At a shear stress of 120 pounds per square inch, the joint with 0.008-inch clearance extended at a rate indicating eventual failure. The joint in the same specimen, but with only 0.004-inch clearance extended only 0.006 inch during the first 7,000 hours and showed no further extension during the next 5,000 hours. It was concluded that 120 pounds per square inch was the maximum allowable shear stress for joints with 0.004-inch clearance, held continuously at 173° F.

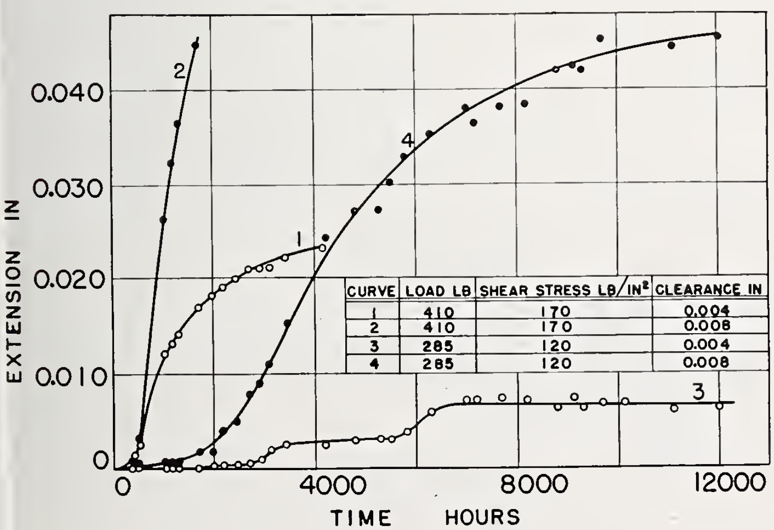


Figure 13.—*Extension-time curves for joints in type L tubing with copper couplings; soldered with (50–50) tin-lead.*

Tests at 173° F.

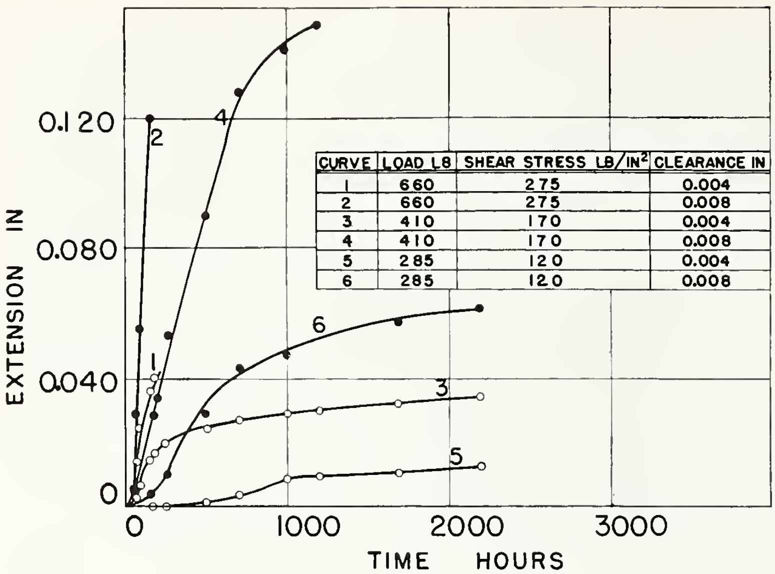


Figure 14.—*Extension-time curves for joints in type L tubing with copper couplings; soldered with (50–50) tin-lead.*

Tests at 218° F.

The curves of figure 14 show that a shear stress of 120 pounds per square inch on the soldered area would cause eventual failure at 218° F. It is evident also that the joints with 0.008-inch clearance extended at a more rapid rate, at each of the three stresses, than did the joints with 0.004-inch clearance.

For the tests at 250° F, all the joints were made with a diametral clearance of 0.004 inch (±0.0006 inch). The specimens were held in a vertical position for making the joints. Hence, for the upper joint in the coupling, the solder ran into the annular space between the tubing and the coupling, aided by gravity, while for the lower joint the solder filled the space by capillary action, against gravity.

For one series of tests the tubing was inserted into the couplings to a depth of 0.87 inch (±0.01 inch). The joints were subjected to tensile loads causing shear stresses on the soldered areas of 70, 80, 90, and 100 pounds per square inch. The tests were continued to 7,500 hours. The observed extensions were plotted against time, in figure 15 for the lower joints and in figure 16 for the upper joints of the specimens. There were no significant differences between the upper and lower joints on the same specimen, indicating that good agreement

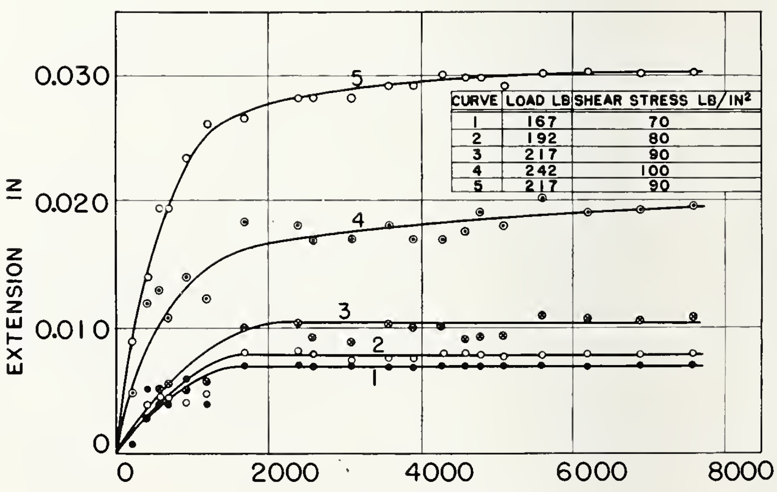
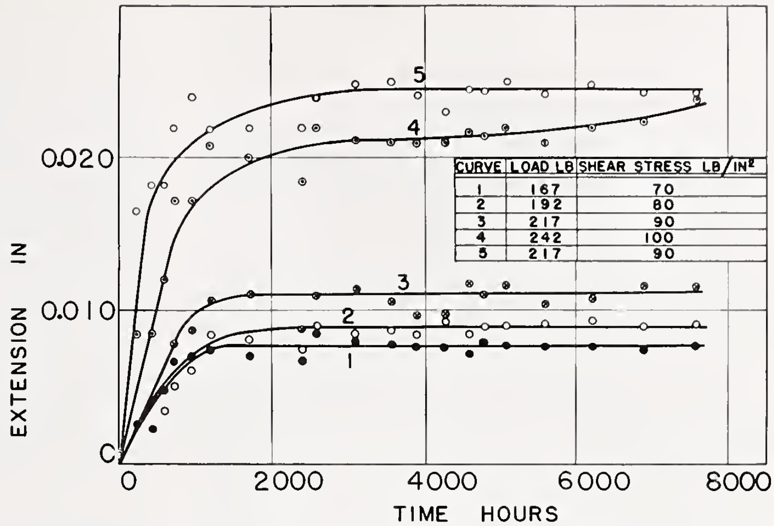


Figure 15.—*Extension-time curves for lower joints in couplings, soldered with (50–50) tin-lead, and tested at 250° F.*

Curves 1, 2, 3, and 4 for copper couplings. Curve 5 for cast-brass (85-5-5-5) coupling. Diametral clearance, 0.004 inch.

Figure 16.—*Extension-time curves for upper joints of same couplings as figure 15.*



can be expected in duplicate specimens. The results also showed that joints filled against gravity can be expected to have the same properties as those made "down-hand" or in a horizontal position.

The joints in copper couplings stressed to 70, 80, and 90 pounds per square inch on the soldered areas extended rather rapidly during the first 1,500 hours at 250° F; but the extensions came to a halt, and the extension-time curves (Nos. 1, 2, and 3, figs. 15 and 16), became horizontal thereafter, indicating permanence under the conditions of test.

The joints stressed at 100 pounds per square inch likewise extended at a more rapid rate during the first 1,500 hours than thereafter; but the joints continued to extend, at a slower rate (curve 4, figs. 15 and 16), to the end of the test, 7,500 hours, indicating eventual failure.

One specimen in the series of tests at 250° F was made with a cast-brass coupling, and the joints were stressed at 90 pounds per square inch. The extensions during the early part of the test (curves 5, figures 15 and 16) were greater than those in the wrought couplings at the same stress, but came to a halt after about 3,000 hours with no further extension to 7,500 hours.

Another series of tests at 250° F were made on specimens in which the joints were made by inserting the tubing into wrought-copper couplings to depths of 0.40, 0.61, 0.87, and 1.50

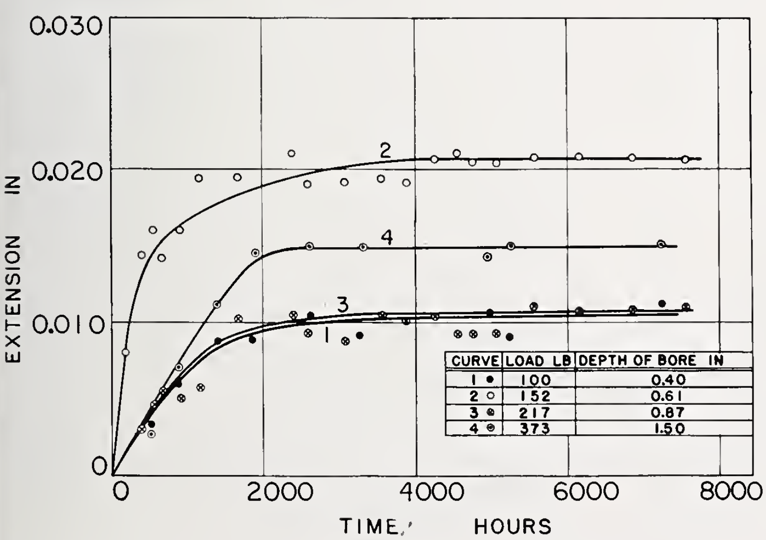


Figure 17.—*Extension-time curves for joints in type L tubing with copper couplings; soldered with (50–50) tin-lead.*

Diametral clearance, 0.004 inch. Depth of insertion varied from 0.40 inch to 1.50 inch. Loads varied accordingly, to make shear stress on soldered area 90 pounds per square inch on each joint. Tests at 250° F.

inches. The specimens were loaded so that the shear stress on the soldered area of each joint was 90 pounds per square inch. The observed extensions, on the lower joints of the couplings only, are plotted against time, to 7,500 hours in figure 17. The extensions of the upper joints were very closely the same as those of the lower joints.

These extension-time curves are in general like those for the joints stressed at 90 pounds per square inch in figures 15 and 16. The results show that increasing the length of soldered area in the joint increases the load-carrying capacity up to the point where the shear stress, on the soldered area, approaches the critical value for the temperature of service.

The rather large differences in total extensions on different specimens, stressed at 90 pounds per square inch on the soldered areas of the joints, and the larger deviations from a uniform rate of extension than were obtained at lower shear stresses were considered to indicate that 90 pounds per square inch was probably on the border line between stresses that would cause eventual failure and those that could be sustained permanently, at 250° F.

It was concluded, therefore, that 80 pounds per square inch was a more conservative value of the maximum allowable shear stress on the soldered area of sleeve-type joints in wrought-copper or cast-brass couplings, made with (50–50) tin-lead solder and held continuously at 250° F.

The marked change to a lower rate of extension after about 1,500 hours at 250° F might be explained by a constitutional change in the tin-lead solder film. A further indication of this was the fact that the load on the specimen stressed at 70 pounds per square inch (curve 1, figs. 15 and 16) was increased after 5,000 hours to cause the shear stress on the soldered area to be 90 pounds per square inch (same value as curve 3, figs. 15 and 16). However, no measurable extension occurred as a result of the increase in stress.

Metallographic examination of solder films from joints held at 250° F for 1,500 hours or more showed that copper had diffused into the tin-lead solder from the brass or copper couplings and from the copper tubing. Increased resistance to shear stresses would be expected from the addition of copper to the tin-lead solder film. Further discussion of this phenomenon is given in a subsequent section of this paper.

VII. MAXIMUM SHEAR-STRESS—TEMPERATURE RELATIONS FOR JOINTS MADE WITH (50–50) TIN-LEAD SOLDER

The maximum allowable shear stresses indicated by the results of the long-time tests at 85°, 123°, 173°, and 250° F described above are listed in table 2 and plotted in figure 18 to show the stress-temperature relation. Joints

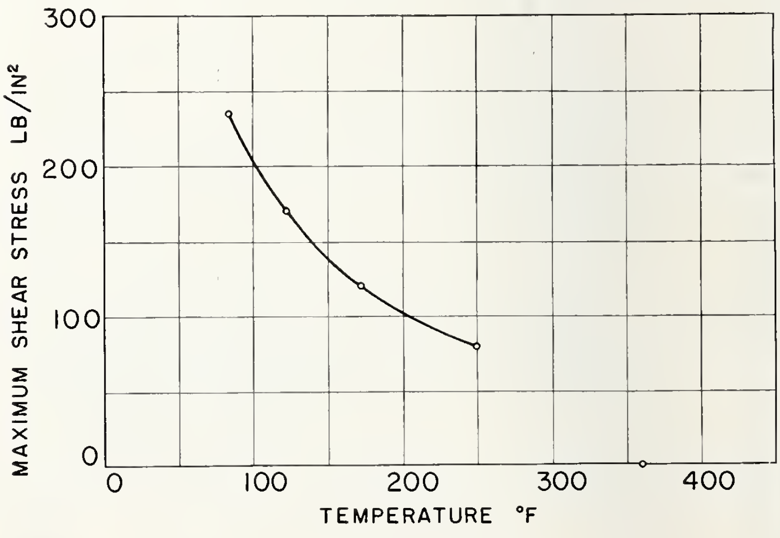


Figure 18.—*Maximum shear stress-temperature relations for joints made with (50–50) tin-lead solder; diametral clearance 0.004 inch.*

with 0.004-inch diametral clearance, made with (50–50) tin-lead solder, can be expected to withstand continuous loading without failure by shear in the solder film when subjected to combinations of stress and temperature, represented by points to the left and below the curve, figure 18. Joints subjected to stresses and temperatures to the right and above this curve can be expected to fail eventually by shear in the soldered film.

It is probably more than a coincidence, and represents the behavior of the materials concerned, that the product of stress and temperature, at the four experimentally determined points, figure 18, is approximately a constant.

Table 2—*Maximum allowable shear stress on soldered areas of joints made with tin-lead and tin-antimony solders, at the indicated temperatures*

Temperature	Tin-lead (50–50)	Tin-antimony (95–5)
°F	*lb/in.²*	*lb/in.²*
85	235	1,200
123	170	-----
173	120	-----
250	80	380
325	---	275

VIII. MAXIMUM INTERNAL-PRESSURE—TEMPERATURE CURVES FOR JOINTS IN COPPER TUBING MADE WITH (50–50) TIN-LEAD SOLDER

The maximum shear stress-temperature relations shown in figure 18 were used by Subcommittee No. 11, American Standards Association Sectional Committee A40, as the basis for establishing internal pressure-temperature ratings in the Proposed American Standard for Soldered-Joint Fittings. In ordinary circumstances the shear stress on the soldered film in sleeve-type joints is caused primarily by the internal pressure in the tubing. At a given pressure the shear stress varies directly with changes in length of the soldered area. As this length is fixed by the dimensions of the fitting, it was desirable to standardize the dimensions of the fittings for the different sizes of tubing. It was obviously impractical to make the depths of the bores of the fittings—that is, the distance to which the tubing is to be inserted into the fitting—such that the shear stresses on the soldered areas at a given pressure would be alike for all the commercial sizes of tubing. Some compromise was necessary to keep the fittings for the larger sizes of tubing to reasonable dimensions.

For the tentative draft of the Proposed American Standard for Soldered Joint Fittings, Subcommittee 11 selected the values given in table 3 for minimum depth of bore, for commercial sizes ⅜ to 6 inches. Joints, in fittings with these depths of bore, made with (50–50) tin-lead solder were considered to have adequate strength for pressures likely to be encountered in ordinary domestic water-service piping. Table 3 gives the internal pressures in ⅜- to 6-inch tubing necessary to develop a shear stress of 235 pounds per square inch on the soldered areas of the joints. The results of the long-time tests described above (see figs. 8 and 9) indicated 235 pounds per square inch as the maximum for sustained loading at room temperature (to 85° F). The pressures were calculated by use of the formula:

$$P=\frac{4L}{D}S,$$

where P is the internal pressure in pounds per square inch (gage), L is the depth of bore (inches), D is the outside diameter of the tubing (inches), S is the shear stress (pounds per square inch).

Table 3.—*Internal pressures corresponding to maximum allowable shear stress on tin-lead soldered areas of joints dimensioned as in columns 1 and 2, and for shear-stress temperature relations as given in figure 18*

Nominal size of tubing [1]	Depth of bore of fitting [2]	Internal pressures			
		235 lb/in.²= max shear stress at 85° F	170 lb/in.²= max shear stress at 123° F	120 lb/in.²= max shear stress at 173° F	80 lb/in.²= max shear stress at 250 °F
Inches	*Inches*	*lb/in.² (gage)*	*lb/in.² (gage)*	*lb/in.² (gage)*	*lb/in.² (gage)*
⅜	⅜	705	510	360	240
½	½	750	545	385	255
¾	¾	805	585	410	275
1	15/16	785	565	400	265
1¼	1	685	495	350	230
1½	1⅛	650	470	330	220
2	1⅜	610	440	310	210
2½	1½	535	390	270	180
3	1 11/16	510	370	260	170
3½	1 15/16	505	365	260	170
4	2 3/16	500	360	255	170
5	2 11/16	495	360	250	170
6	3⅛	480	350	245	165

[1] ASTM and Federal specifications.
[2] ASA proposed standard.

The maximum pressures that can be maintained without eventual failure decrease with

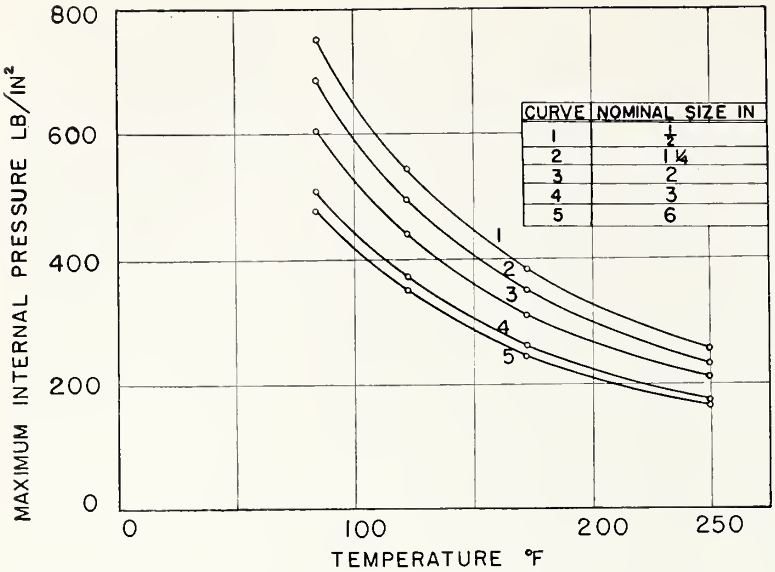


FIGURE 19.—*Maximum internal pressure-temperature relations for joints in various sizes of copper tubing made with (50–50) tin-lead solder.*

increase in temperature, in the same relation as do the shear stresses (fig. 18). With the above formula the internal pressures corresponding to the maximum shear stresses at 123°, 173°, and 250° F have been calculated for sizes from ⅜ to 6 inches. These values are also included in table 3. The curves, figure 19, show the maximum internal pressure-temperature relations for (50–50) tin-lead soldered joints for some of the commercial sizes of tubing. These relations for sizes not in the range plotted can be gotten by interpolation.

Apart from the fact that the fittings should not be rated for pressures corresponding to the maximum strength of the soldered joints, allowance should be provided for imperfectly soldered joints and for stresses imposed on the joints from sources other than the internal pressure in the tubing. Subcommittee 11 decided that an ample margin of safety would be provided by the ratings in table 4, selected for the tentative draft of the Proposed Standard for Soldered-Joint Fittings. These ratings fall well below the curves, figure 19.

TABLE 4.—*Pressure ratings for joints made with (50–50) tin-lead solder* [1]

Service temper-tures	Service pressure ratings at temperatures from 100° to 250° F		
	Fluids other than steam		Steam
	Nominal sizes 2 in. and smaller	Nominal sizes 2½ in. and larger	Nominal sizes all
°F	*lb/in.² (gage)*	*lb/in.² (gage)*	*lb/in.² (gage)*
100	175	150	----
150	125	100	----
200	100	75	----
250	75	50	15

[1] Pressure ratings are less than half the values shown on figure 19. Joints made with (50–50) tin-lead solder are not recommended for temperatures above 250° *F*.

The determination of the ratings for these fittings illustrates a practical use of the results of the strength tests described in the foregoing sections of this paper.

IX. JOINTS MADE WITH (95–5) TIN-ANTIMONY SOLDER

The short-time tensile tests at room and at elevated temperatures, described in section V, showed that joints soldered with (95–5) tin-antimony alloy required much greater loads to cause rupture in the solder films than did joints soldered with (50–50) tin-lead alloy. The short-time tests showed also that the tin-antimony soldered joints did not lose strength as rapidly as did the tin-lead soldered joints when the temperature was raised above 85° F.

1. LONG-TIME TESTS AT ROOM TEMPERATURE (ABOUT 85° F)

Specimens similar to those used for the tests on tin-lead soldered joints were prepared for sustained tensile load tests on joints made with (95–5) tin-antimony solder. The tests were made at 85°, 250°, and 325° F. For the tests at 85° F, four specimens, each containing four couplings, were used. Two of the couplings were cast brass and two were wrought copper. The upper joint of each coupling was made with 0.008-inch diametral clearance and the lower with 0.004-inch clearance. Most of the joints made with the larger clearance failed at shear stresses that did not cause measurable extensions in the joints with 0.004-inch clearance.

The results of the tests at 85° F carried to 7,500 hours showed that the joints with 0.004 inch (±0.0006 inch) clearance, consisting of ¾-inch type K tubing soldered into copper or cast-brass couplings, would withstand without failure sustained tensile loads causing shear stresses on the soldered area up to 1,200 pounds per square inch. This was about five times the stress obtained for (50–50) tin-lead soldered joints in similar tests.

A noteworthy observation was that no measurable extensions were obtained in the tin-antimony soldered joints prior to visible rupture. Extension-time curves such as were obtained for the tin-lead soldered joints (figs. 8 and 9) could not, therefore, be plotted.

2. Long-Time Tests at 250° and 325° F

For the sustained-load tests at elevated temperatures, the specimens and equipment were like those used for similar tests on the tin-lead soldered joints, figures 10 and 11. At 250° F, four specimens, each with two joints, were subjected to loads causing shear stresses on the soldered area of 590, 540, 480, and 430 pounds per square inch, respectively. All failed by rupture of the solder film, without previous visible extension (more than 0.001 inch), in from 920 hours for the most heavily loaded to 3,600 hours for the joint under the lowest stress. Additional specimens loaded to shear stresses on the soldered area of 380 and 350 pounds per square inch did not fail to show any significant extension in the joints in 5,000 hours. These results could be considered to indicate that joints between copper tubing and copper sleeves made with (95–5) tin-antimony solder, would support continuously, at 250° F, tensile loads causing shear stresses in the soldered films not exceeding 380 pounds per square inch.

It was found, however, upon examination of segments cut from such joints, that had been exposed continuously to 250° F, for several thousand hours, that the bond between the solder and copper had been significantly weakened. The segment of tubing could be "peeled" from the surrounding piece of coupling by hand. Metallographic examination showed that this condition resulted from diffusion between the copper and solder.

Examination of similarly soldered joints exposed to a temperature of 325° F for several thousand hours and more showed that interdiffusion between copper and the tin-alloy solder was more pronounced than at 250° F. In segments cut from the joints, the tubing dropped from the surrounding coupling without application of any force. The "solder" film was slate-colored and very brittle, and could be "peeled" from the copper. The surface of the copper, was blackened, apparently by an oxide film.

In the sustained tensile-load tests at 325° F, the joints were initially subjected to loads causing shear stresses on the soldered areas of 80 to 275 pounds per square inch without any significant extensions in 2,500 hours. The loads were increased at intervals, until failures were obtained, after 7,500 hours, in the joints having shear stresses exceeding 400 pounds per square inch. The failures occurred by rupture in the solder film without any previous extension. However, joints loaded initially to a shear stress (on the soldered area) of 400 pounds per square inch failed within a few days, with considerable extension before rupture took place in the solder film.

Evidently, despite the loss of bonding strength that initially exists between the solder and the copper resulting from diffusion in the solder film, the joint is "keyed" against slipping to an extent that permits the joint to support higher loads than can be supported initially. Such joints, not retaining the original continuous metal bond between the solder and the copper, are not necessarily leak-proof and would be expected to be subject to localized corrosion along the solder film.

Observations on joints soldered with pure tin confirmed the indications that the rate of diffusion between copper and tin-alloy soft solders increased with increase in tin content of the solder.

Although the maximum stress that could be supported continuously without failure at 325° F was not determined, the results of the tests, extended to 7,500 hours indicated that joints made with the tin-antimony solder would not fail under shear stresses not exceeding 275 to 300 pounds per square inch (at 325° F).

However because of the diffusion that takes place between the tin-alloy solders and copper at temperatures above about 250° F, and the resulting loss of bonding strength, it is considered that such solders should not be used in joints subjected continuously to temperatures above 250° F.

X. MAXIMUM SHEAR-STRESS—TEMPERATURE RELATIONS FOR JOINTS MADE WITH (95–5) TIN-ANTIMONY SOLDER

The results of the long-time tests at 85°, 250°, and 325° F indicated that the maximum allowable shear-stresses on the soldered areas of joints in copper tubing soldered into copper sleeves with (95–5) tin-antimony alloy were as listed in table 2. Although tests at other temperatures, particularly between 85° and 250° F, should be made to locate accurately the stress-temperature relations shown by the curve, figure 20, it is considered that the maximum allowable stresses at all temperatures between 85° and 250° F can be estimated with sufficient accuracy for design purposes from this curve. Prolongation of the curve beyond the 250° F point should not be considered justification for use of this solder at temperatures in this range.

The maximum stress-temperature curve for joints soldered with tin-lead alloy (fig. 18) has been replotted, to a different scale for stress, in figure 20, for a comparison with a similar curve for joints made with tin-antimony solder. It is evident that the pressure ratings, table 4 and figure 19, provide a considerably greater margin of safety with the (95–5) tin-antimony solder than with the (50–50) tin-lead solder, at temperatures up to 250° F.

XI. FLUCTUATING TENSILE LOAD TESTS ON JOINTS MADE WITH (50–50) TIN-LEAD SOLDER

The tests described in the foregoing sections were made under continuous loading without intermittent unloading. Piping in household plumbing, as well as in other installations, is subject to vibration. It was considered that the behavior of soft-soldered joints in copper tubing under repeated stressing, such as would occur in vibratory action, was of sufficient importance to warrant investigation.

Specimens consisting of type L copper tubing soldered into wrought-copper couplings with (50–50) tin-lead alloy were subjected to pulsating tensile loads in machines used previously

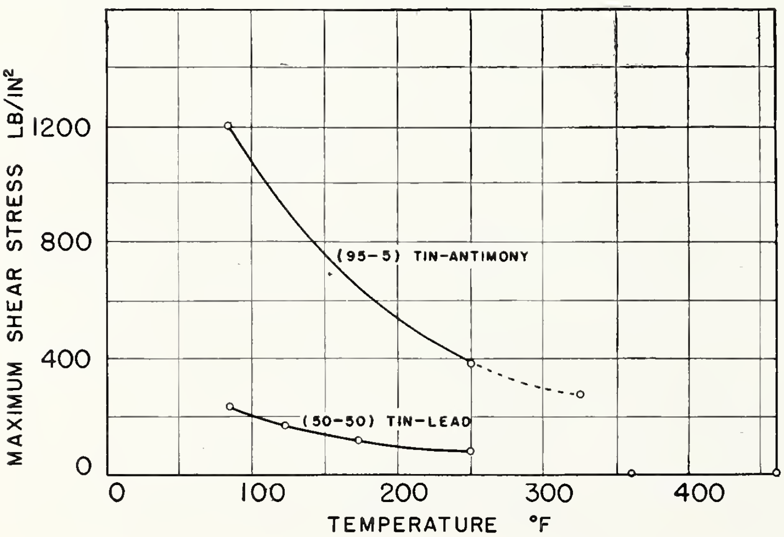


FIGURE 20.—*Maximum shear stress-temperature relations for joints made with tin-antimony and tin-lead solders.*

Lower curve is same as figure 18, drawn to different scale for stress.

for pulsating tensile-load tests on wire.[6] The loads ranged from the minimum available, which produced a shear stress on the soldered area of the joint equal to 40 pounds per square inch, to those which caused failure by fracture of the coupling or tubing or by shear in the solder film, after a few thousand cycles. The loads changed from minimum to maximum 20 to 25 times per minute. All tests were made at room temperature.

It was found that at a range of shear stress on the soldered area of 300 pounds per square inch (40 to 340 pounds per square inch) or less, failures were not obtained in 2 million cycles. Tests were not continued beyond this number of cycles. It was considered more important to obtain data on a number of specimens under similar stress ranges than to prolong the test to the conventional 10 million (for steels) or 100 million (nonferrous) cycles used in determinations of fatigue limits.

Four specimens were tested at the stress range of 300 pounds per square inch. The tensile load ranged from 96 to 720 pounds. On two of the joints the extensions, after 2 million cycles, were of the order of 0.001 inch, an amount considered to be insignificant. On the other two joints the extensions were 0.009 and 0.021 inch, respectively, amounts indicating the joints would ultimately fail if the stressing were continued. At higher stress ranges, fractures were obtained in the solder films and in the couplings or tubing. As 235 pounds per square inch was determined to be the maximum stress, on the soldered area, that could be withstood without eventual failure by joints subjected to steady tensile loads, the results of the pulsating tensile-load tests were considered to indicate that this limit would apply also to joints loaded repeatedly in tension.

With the equipment available, it was not possible to make repeated loading tests on soldered joints with the load cycle ranging from tension to compression.

XII. SUMMARY

1. Short-time and long-time tensile tests have been made on sleeve-type joints in types K and L copper tubing, soldered into wrought-copper and cast-brass couplings with (50–50) tin-lead and (95–5) tin-antimony alloys.

2. A number of investigations made elsewhere have shown the marked decrease in strength of tin and lead alloys similar to those commonly used as soft solders, as temperature and time under load are increased. However, the strength of soldered joints, including sleeve-type joints in copper tubing, cannot be estimated from results of tests on specimens of the solder alloys themselves.

3. In addition to time and temperature, other variables affecting the strength of sleeve-type joints in tubing include:

(a) Depth of bore in the fitting.

(b) Diametral clearance, that is, thickness of the annular space between tubing and fitting, filled with solder.

(c) Kind of metal used for fittings.

4. Short-time tensile tests showed that the strength of joints soldered with (50–50) tin-lead solder increased in an approximately direct proportion to the increase in depth of bore in wrought-copper and cast-brass fittings (fig. 1). In straight couplings conforming to commercial standards the depths of bore are sufficient so that, in short-time tensile tests, the strength of the soldered joints is substantially equal to that of the coupling or tubing.

5. Results of short-time tensile tests at room temperature showed that joints made with (50–50) tin-lead and (95–5) tin-antimony solders with diametral clearances up to 0.010 inch were slightly stronger than were similar joints with greater clearances. The joints soldered with (95–5) tin-antimony were about 13 percent stronger at all clearances (to 0.06 inch) than were those soldered with (50–50) tin-lead (fig. 4).

6. Joints in which one member was yellow brass (60 copper, 40 zinc) soldered with (50–50) tin-lead, had slightly lower strength at small diametral clearances than at clearances greater than about 0.010 inch. When the same joints were resoldered twice, the strength at the smaller clearances increased. Further investigation indicated that this behavior was related to absorption by the solder of zinc from the brass (fig. 3).

7. In short-time tensile tests, copper-to-copper joints with nominal clearance (0.004 inch), soldered with the eutectic composition of

[6] W. H. Swanger and G. F. Wohlgemuth, *Failure of heat-treated steel wire in cables of Mt. Hope R. I. suspension bridge*, Proceedings American Society for Testing Materials **36**, fig. 14, p. 48, and fig. 24, p. 69 (1936).

tin-lead (63 percent tin, 37 percent lead) had higher strength than similar joints soldered with pure lead, pure tin, or other proportions of tin and lead (fig. 5).

8. In short-time tensile tests (speed of movable head 0.06 inch per minute) the strength of joints soldered with (50–50) tin-lead, calculated as shear stress on the soldered area for maximum load, decreased from 8,000 pounds per square inch at 0° F to 600 pounds per square inch at 350° F. For similar joints soldered with (95–5) tin-antimony, the maximum shear stress decreased from 8,300 pounds per square inch at 0° F to 1,800 pounds per square inch at 325° F (fig. 6).

9. The results of sustained tensile-load tests at room temperature (85° F), continued as long as 10,000 hours, indicated that the maximum shear stress on the soldered area without extensions indicating eventual failure was 235 pounds per square inch for joints in ¾-inch tubing made with (50–50) tin-lead solder. This value held for cast brass (85 copper, 5 tin, 5 zinc 5, lead) as well as for wrought-copper couplings, and for diametral clearances of 0.004 and 0.008 inch. This value was also found to hold for similar joints in 3-inch tubing (figs. 8 and 9).

10. Results of long-time (7,500 to 8,500 hours) tests under sustained tensile loads at temperatures above 85° F showed that the maximum shear stress on the soldered area that could be supported without extension indicating eventual failure, in joints soldered with (50–50) tin-lead, was 170 pounds per square inch at 123° F (fig. 12), 120 pounds per square inch at 173° F (fig. 13), less than 120 pounds per square inch at 218° F (fig. 14), and only 80 pounds per square inch at 250° F (figs. 15, 16, and 17). These values hold for wrought-copper and cast-brass fittings, with diametral clearances of 0.004 inch. Joints having clearances of 0.008 inch may fail at the above stresses.

11. From the maximum shear-stress–temperature relations (fig. 18 and table 2) the corresponding internal pressures, in pounds per square inch gage, were calculated for the nominal tube sizes ⅜ to 6 inches (fig. 19 and table 3).

12. In the Proposed American Standard for Soldered-Joint Fittings prepared by Subcommittee No. 11, American Standards Association Section Committee A40, the adjusted pressure ratings for joints made with (50–50) tin-lead solder (table 4) were based on the maximum shear-stress–temperature relations given in this paper (fig. 18 and table 2).

13. Results of sustained tensile-load tests at 85° F showed that joints in ¾-inch tubing soldered with (95–5) tin-antimony solders and wrought-copper or cast-brass couplings withstood shear stresses on the soldered area up to 1,200 pounds per square inch without extension indicating eventual failure. This value is five times that determined for similar joints soldered with (50–50) tin-lead.

14. At 250° and 325° F the maximum allowable shear stresses for joints soldered with (95–5) tin-antimony were found to be 380 and 275 pounds per square inch, respectively. The maximum shear-stress–temperature curve for (95–5) tin-antimony soldered joints is therefore considerably higher than that for (50–50) tin-lead soldered joints (fig. 20). In the long-time tests of the joints soldered with (95–5) tin-antimony, failure generally occurred by rupture in the solder film, without prior extension of the joint. In the joints soldered with (50–50) tin-lead, an increasing rate of extension of the joint was the criterion of failure.

15. In the long-time tests on joints soldered with (95–5) tin-antimony those with a diametral clearance of 0.008 inch extended more than did those with a clearance of 0.004 inch at the same stresses.

16. In the joints used in the elevated-temperature tests, diffusion of copper into the solder films was found to occur at temperatures of 250° F and above. The diffusion increases with increase in temperature above 250° F, and also with increase in tin content of the solder. In joints soldered with (95–5) tin-antimony, exposed for 5,000 hours at 325° F, the metallic bond between the solder and the tubing was destroyed. At 250° F the bond was significantly weakened. With (50–50) tin-lead solder, diffusion at 250° F is considerably slower. The results of the elevated-temperature tests indicated that joints in copper tubing made with tin or tin-alloy solders should not be subjected continuously to temperatures above 250° F.

17. Results of pulsating tensile-load tests at room temperature indicated that joints soldered

with (50–50) tin-lead solder could withstand for 2 million cycles repeated stressing to the maximum shear stress on the soldered area found for sustained tensile loading.

Acknowledgment is made for assistance in the conduct of this investigation received from various members of the staff of the National Bureau of Standards, particularly the Division of Metallurgy. Grateful acknowledgment is made also for helpful advice and suggestions received from J. A. Doucett, Chairman, Executive Committee, and B. B. Caddle, Secretary, Copper and Brass Research Association.

XIII. SELECTED REFERENCES

[1] G. O. Hiers, *Soft solders and their applications*, Metals & Alloys **2**, 257 (1931).

[2] S. J. Nightingale, The Jointing of Metals. Part I. Soft Solders and Soldered Joints, Brit. Non-Ferrous Metals Research Assn., Research Reports, No. C 234/214 (Dec. 1936).

[3] D. J. Macnaughtan, E. S. Hedges, and W. R. Lewis, Solder, Int. Tin Research Development Council, Bul. No. 2 (1935).

[4] B. W. Gonser and C. M. Heath, *Physical properties of soft solders and the strength of soldered joints*, Trans. Am. Inst. Mining Met. Engrs. **122**, 349 (1936).

[5] I. T. Hook, *Methods of joining copper alloy products, parts I, II, and III, Tubes, etc.*, Metal Ind. (N. Y.) **35**, 434, 498, and 555 (1937).

[6] E. J. Daniels and D. J. Macnaughtan, The Wetting of Metals by Metals with Particular Reference to Tinning and Soldering, Tech. Pub. Int. Tin Research Development Council, [B] No. 6 (1937).

[7] A. W. Coffman and S. W. Parr, *Surface tension of metals with reference to soldering conditions*, Ind. Eng. Chem. **19**, 1308 (1927).

[8] R. S. Dean and R. V. Wilson, *Action of fluxes in soft soldering and a new class of fluxes for soft soldering*, Ind. Eng. Chem. **19**, 1312 (1927).

[9] A. Eyles, *Some practical notes on solders and soldering fluxes*, Metal Ind. (London) **40**, 3 (1932).

[10] C. L. Barber; *Soft solder fluxes*, Ind. Eng. Chem. **29**, 1114 (1937).

[11] J. R. Freeman, Jr., and G. W. Quick, *Tensile properties of soldered joints under prolonged stress*, Metal Ind. (N. Y.) **24**, 7 (1926).

[12] R. Chadwick, *The influence of surface alloying on the strength of soft soldered joints*, J. Inst. Metals **62**, 277 (1938).

[13] C. W. Hill and C. H. Carpenter, *Strength of solders at elevated temperatures*, Metal Ind. (N. Y.) **17**, 82 (1919).

[14] D. Hanson and E. J. Sandford, *The creep of tin and tin alloys—Part I*, J. Inst. Metals **59**, 159 (1936).

[15] J. McKeown, *Creep of lead and lead alloys. Part I—Creep of virgin lead*, J. Inst. Metals **60**, 201 (1937).

[16] W. A. Baker, *The creep properties of soft solders and soft-soldered joints*, J. Inst. Metals **65**, 277 (1939).

[17] M. S. Noyes, *The Navy's soldered fittings*, J. Am. Soc. Naval Engrs. **47**, 57 (1935).

Washington, May 24, 1940.

BUILDING MATERIALS AND STRUCTURES REPORTS

On request, the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., will place your name on a special mailing list to receive notices of new reports in this series as soon as they are issued. There will be no charge for receiving such notices.

An alternative method is to deposit with the Superintendent of Documents the sum of $5.00, with the request that the reports be sent to you as soon as issued, and that the cost thereof be charged against your deposit. This will provide for the mailing of the publications without delay. You will be notified when the amount of your deposit has become exhausted.

If 100 copies or more of any report are ordered at one time, a discount of 25 percent is allowed.

Send all orders and remittances to the *Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.*

The following publications in this series are available by purchase from the Superintendent of Documents at the prices indicated:

BMS1	Research on Building Materials and Structures for Use in Low-Cost Housing	10¢
BMS2	Methods of Determining the Structural Properties of Low-Cost House Constructions	10¢
BMS3	Suitability of Fiber Insulating Lath as a Plaster Base	10¢
BMS4	Accelerated Aging of Fiber Building Boards	10¢
BMS5	Structural Properties of Six Masonry Wall Constructions	15¢
BMS6	Survey of Roofing Materials in the Southeastern States	15¢
BMS7	Water Permeability of Masonry Walls	10¢
BMS8	Methods of Investigation of Surface Treatment for Corrosion Protection of Steel	10¢
BMS9	Structural Properties of the Insulated Steel Construction Co.'s "Frameless-Steel" Constructions for Walls, Partitions, Floors, and Roofs	10¢
BMS10	Structural Properties of One of the "Keystone Beam Steel Floor" Constructions Sponsored by the H. H. Robertson Co	10¢
BMS11	Structural Properties of the Curren Fabrihome Corporation's "Fabrihome" Constructions for Walls and Partitions	10¢
BMS12	Structural Properties of "Steelox" Constructions for Walls, Partitions, Floors, and Roofs Sponsored by Steel Buildings, Inc	15¢
BMS13	Properties of Some Fiber Building Boards of Current Manufacture	10¢
BMS14	Indentation and Recovery of Low-Cost Floor Coverings	10¢
BMS15	Structural Properties of "Wheeling Long-Span Steel Floor" Construction Sponsored by the Wheeling Corrugating Co	10¢
BMS16	Structural Properties of a "Tilecrete" Floor Construction Sponsored by Tilecrete Floors, Inc	10¢
BMS17	Sound Insulation of Wall and Floor Constructions	10¢
BMS18	Structural Properties of "Pre-Fab" Constructions for Walls, Partitions, and Floors Sponsored by the Harnischfeger Corporation	10¢
BMS19	Preparation and Revision of Building Codes	15¢
BMS20	Structural Properties of "Twachtman" Constructions for Walls and Floors Sponsored by Connecticut Pre-Cast Buildings Corporation	10¢
BMS21	Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association	10¢
BMS22	Structural Properties of "Dun-Ti-Stone" Wall Construction Sponsored by the W. E. Dunn Manufacturing Co	10¢
BMS23	Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc	10¢
BMS24	Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute	10¢
BMS25	Structural Properties of Conventional Wood-Frame Constructions for Walls, Partitions, Floors, and Roofs	15¢
BMS26	Structural Properties of "Nelson Pre-Cast Concrete Foundation" Wall Construction Sponsored by the Nelson Cement Stone Co., Inc	10¢
BMS27	Structural Properties of "Bender Steel Home" Wall Construction Sponsored by The Bender Body Co	10¢
BMS28	Backflow Prevention in Over-Rim Water Supplies	10¢

[List continued on cover page IV]

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page III]

BMS29 Survey of Roofing Materials in the Northeastern States ---- 10¢
BMS30 Structural Properties of a Wood-Frame Wall Construction Sponsored by the Douglas Fir Plywood Association ---- 10¢
BMS31 Structural Properties of "Insulite" Wall and "Insulite" Partition Constructions Sponsored by The Insulite Co ---- 15¢
BMS32 Structural Properties of Two Brick-Concrete-Block Wall Constructions and a Concrete-Block Wall Construction Sponsored by the National Concrete Masonry Association ---- 10¢
BMS33 Plastic Calking Materials ---- 10¢
BMS34 Performance Test of Floor Coverings for Use in Low-Cost Housing: Part 1 ---- 10¢
BMS35 Stability of Sheathing Papers as Determined by Accelerated Aging ---- 10¢
BMS36 Structural Properties of Wood-Frame Wall, Partition, Floor, and Roof Constructions with "Red Stripe" Lath Sponsored by the Western Paper and Manufacturing Co ---- 10¢
BMS37 Structural Properties of "Palisade Homes" Constructions for Walls, Partitions, and Floors, Sponsored by Palisade Homes ---- 10¢
BMS38 Structural Properties of Two "Dunstone" Wall Constructions Sponsored by the W. E. Dunn Manufacturing Co ---- 10¢
BMS39 Structural Properties of a Wall Construction of "Pfeifer Units" Sponsored by the Wisconsin Units Co ---- 10¢
BMS40 Structural Properties of a Wall Construction of "Knap Concrete Wall Units" Sponsored by Knap America, Inc ---- 10¢
BMS41 Effect of Heating and Cooling on the Permeability of Masonry Walls ---- 10¢
BMS42 Structural Properties of Wood-Frame Wall and Partition Constructions with "Celotex" Insulating Boards Sponsored by the Celotex Corporation ---- 10¢
BMS43 Performance Test of Floor Coverings for Use in Low-Cost Housing: Part 2 ---- 10¢
BMS44 Surface Treatment of Steel Prior to Painting ---- 10¢
BMS45 Air Infiltration Through Windows ---- 10¢
BMS46 Structural Properties of "Scot-Bilt" Prefabricated Sheet-Steel Constructions for Walls, Floors, and Roofs Sponsored by the Globe-Wernicke Co ---- 10¢
BMS47 Structural Properties of Prefabricated Wood-Frame Constructions for Walls, Partitions, and Floors Sponsored by American Houses, Inc ---- 10¢
BMS48 Structural Properties of "Precision-Built" Frame Wall and Partition Constructions Sponsored by the Homasote Co ---- 10¢
BMS49 Metallic Roofing for Low-Cost House Construction ---- 10¢
BMS50 Stability of Fiber Building Boards as Determined by Accelerated Aging ---- 10¢
BMS51 Structural Properties of "Tilecrete Type A" Floor Construction Sponsored by the Tilecrete Corporation ---- 10¢
BMS52 Effect of Ceiling Insulation on Summer Comfort ---- 10¢
BMS53 Structural Properties of a Masonry Wall Construction of "Munlock Dry Wall Brick" Sponsored by the Munlock Engineering Co ---- 10¢
BMS54 Effect of Soot on the Rating of an Oil-Fired Heating Boiler ---- 10¢
BMS55 Effect of Wetting and Drying on the Permeability of Masonry Walls ---- 10¢
BMS57 Roofing in the United States—Results of a Questionnaire ---- 10¢
BMS58 Strength of Soft-Soldered Joints in Copper Tubing ---- 10¢