RP216

SEAMS FOR COPPER ROOFING

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ABSTRACT

The various types of seams which have been proven by experience to be suitable for copper roofing are described. The ribbed or batten, the standing and the open-lock types give rise to no difficulties, if properly made, and, therefore, no tests of these seams were necessary.

While flat-lock seams calked with white lead and linseed oil have given very satisfactory service in the past, a quantitative measure of the water-tightness of these seams is desirable. Leakage tests showed that calked seams can be used wherever the depth of water which may be standing for several days on the roof will not exceed 4 inches, a depth rarely occurring except in gutters. A small section of seam removed from a roof after many years of service stood continuously for 45 days under 12 inches of water without any signs of leaking.

Tensile tests of one-half-inch flat lock and of lap seams yielded the following results:

1. Seams made with resin, killed acid, or a commercial "prepared" flux are equally strong.
2. Seams made parallel to or transverse to the direction of rolling of the copper are equally strong.
3. The strength of lap seams, one-fourth to 1 inch wide, is proportional to the width.
4. On one-half-inch flat-lock seams a large increase in the amount of solder used results in only a small increase in strength.
5. Pretinning by dipping the edges of the sheets to be joined in solder or tin increases the strength very greatly in the case of flat-lock seams.

The last two of these conclusions are of considerable importance, for it is believed by many roofers that a strong flat-lock seam can only be secured by the lavish use of solder. The tests proved, however, that the maximum strength is secured by pretinning, and large quantities of solder on the exposed surface of the seams are of little value.

The results of prolonged loading tests indicated that the maximum safe load for soldered lap seams is about 350 lbs./in.^{2} of seam and about 375 lbs./in.^{2} pretinned flat-lock seams. Under greater loads failure occurs after a time, depending on the magnitude of the load.

CONTENTS

I. INTRODUCTION

The value of a sheet-metal roof in protecting a building from the destructive agencies of the weather is dependent in great measure on the character of the seams which join the sheets. With copper roofing, chosen primarily for long life, it is essential to secure durable weatherproof seams. Most of the various types of seams which experience has demonstrated to be suitable for copper roofing give uniformly satisfactory service. With some types, however, difficulties are occasionally experienced. Often these difficulties can be attributed to improper construction, but sometimes they can not be readily explained without a more complete knowledge of the properties of the seams. It is the purpose of this investigation to provide the additional data needed. The investigation is part of a study of copper

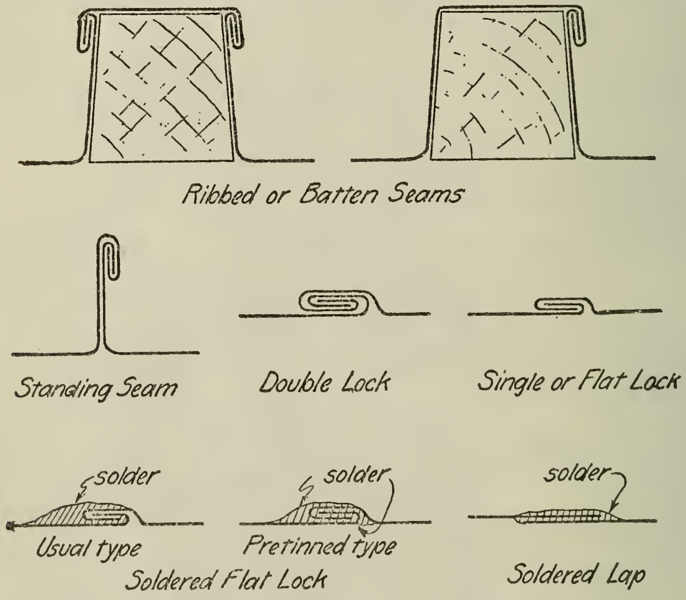

FIGURE 1.—*Types of seams suitable for copper roofing*

roofing problems conducted by the Copper & Brass Research Association and the National Bureau of Standards.

The seams commonly used for copper roofing are shown in Figure 1. Which type is to be chosen in any particular case depends on the design of the roof. The loosely locked types which very rarely cause trouble are suitable only for fairly steep, freely draining surfaces. On nearly level roofs and in gutters, where water may collect to an appreciable depth, either calked or soldered seams are required. If the appearance of the roof is important from the architectural standpoint, then the form and arrangement of the seams must be taken into account.

Two other considerations must always be kept in mind in any discussion of seams. First, it is essential that proper allowance be made at the seams for the expansion and contraction of the copper sheets resulting from temperature changes. Otherwise the seams may be subjected to excessive stress and injured to the extent that their resistance to the weather is destroyed. Second, some means must be provided for attaching the sheets to the supporting roof structure. Cleats, as shown in Figure 18, consisting of bent pieces of copper with one end hooked into the seam and the other end nailed to the roof, have been found to be the best means of attachment for copper roofing. Cleats improperly made or poorly placed may be the cause of damage to seams.

For reference, a comparison between the gage number and the nominal thickness of sheet copper, for the gages mentioned in this paper, is given in Table 1. The gage number is defined by the weight of the sheet in ounces per square foot. Sixteen-ounce copper is the gage most often used. Lighter gages are not satisfactory for roofing purposes.

TABLE 1.—*Gage number and thickness of sheet copper*

Gage No. (in ounces per square foot)	Nominal thickness
	Inch
14	0.0189
16	.0216
18	.0243
20	.0270

II. RIBBED AND STANDING SEAMS

Ribbed or batten seams may be made in several ways, two of which are illustrated in Figure 1. Since these seams will leak if standing under water, they can be used only on roofs of considerable pitch. To prevent interference with free drainage they are always laid in a direction perpendicular to the eaves. Ribbed seams make adequate allowance for temperature changes as the sheets are free to expand or contract slightly at the base of the ribs and also in the loose locks at the top of the ribs. This type is best suited for large structures where appearance is of great importance.

Experience has shown that ribbed seams give satisfactory service and, therefore, no tests were necessary.

The standing seam (fig. 1) is cheaper and, therefore, used more often than the ribbed seam. Like the ribbed seam, it is suitable only for fairly steep roofs, and must be laid perpendicular to the eaves. Standing seams should be neither soldered nor riveted for the additional restraints imposed are apt to result in unsightly buckling of the sheets and, in extreme cases, tearing or cracking. An example of what may happen when standing seams are riveted is shown in Figure 2.

No tests were made on standing seams, since they give rise to no troubles if made according to recommended practice.

III. FLAT SEAMS, DOUBLE AND SINGLE LOCK

The open double-lock and single-lock seams (fig. 1) are used for the cross seams between ribbed or standing seams, and, in general, on steep slopes where there must not be any obstruction to the free flow of water. Obviously, they are unsuitable for places where water may be standing on the roof because the water will gradually seep through the locks. These seams are very rarely subject to injury due to temperature changes, since there is ample allowance in the locks for slight relative movements of the adjacent sheets.

The double-lock seam is not often used, chiefly because there are six thicknesses of metal in the lock. It is therefore very difficult to secure a good joint where one seam meets another at right angles. The single lock, commonly called a flat-lock seam, is free from this objection and is also more economical of material.

No tests were made on these open-lock seams for they rarely cause any difficulties.

IV. CALKED SEAMS

A calked seam is made by coating the edges of the sheets to be joined with a thick paste of white lead and linseed oil and then forming a flat lock. If properly made, the seam is completely filled with the white lead. The practice of calking flat-lock seams was quite common 30 or 40 years ago, but has died out to a great extent at present. Possibly the laborious and dirty job of mixing the dry lead with the oil as it was required brought about the more extensive use of solder to take the place of calking. The white lead in paste form can now be purchased ready mixed, so that this objection is no longer of any moment.

Calked seams possess several advantages. They can be used on roofs of very flat slope and other places where the ordinary lock seam would leak. As compared with soldered seams they are cheaper, better in appearance, and less likely to be damaged by temperature effects because the connection between the sheets is not so rigid and a slight amount of relative movement is possible.

Although calked seams have proven successful on numerous buildings, the State House in Boston being a notable example, a need has been felt for some quantitative measure of their proof against leakage. Accordingly, tests were made to determine the head of water which a calked seam can support.

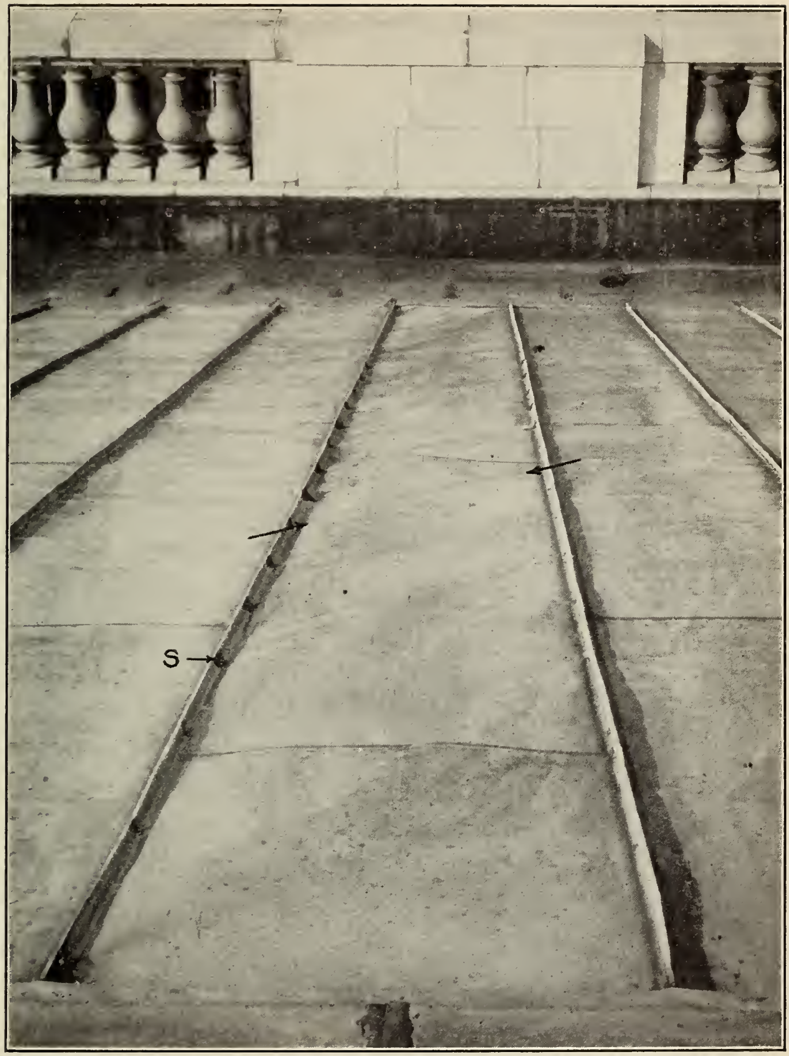

Figure 2.—*Diagonal buckling and tearing of copper due to riveting of standing seams*

The row of sheets in the center of the photograph lies directly over an expansion joint in the concrete roof. If there had been no rivets, a large part of the movement caused by temperature changes would have been taken up by slipping of the sheets relative to each other in the seams. This slipping was prevented by the rivets. Note the excessive buckles running diagonally across the sheets, one of which is indicated by the arrows. The copper was torn at the rivets at all the dark spots (as at *S*). These spots are patches applied to stop leaking.

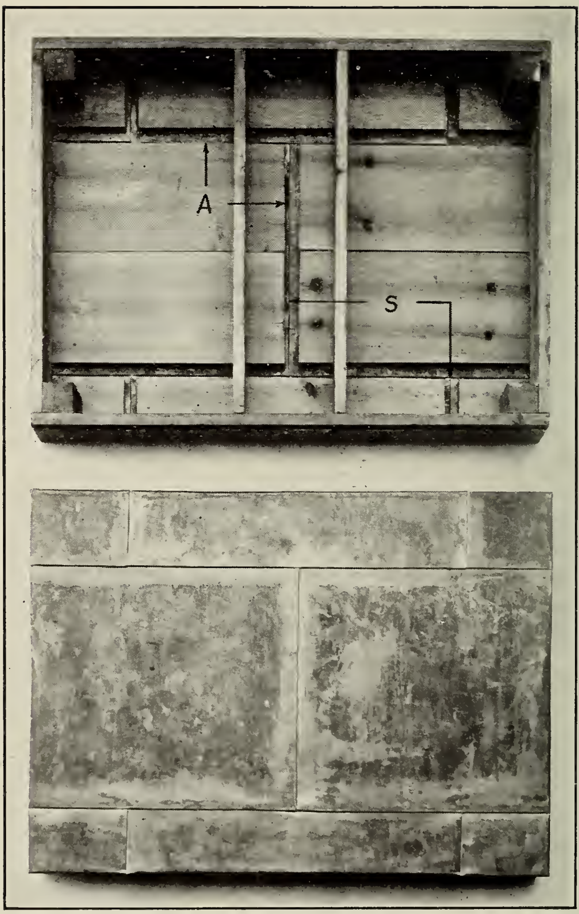

Figure 3.—*Roof specimens with new calked seams for leakage tests*

Upper view shows specimen from beneath. Sheathing cut away at *A* to expose lower surfaces of seams *S*. Lower view shows top of specimen.

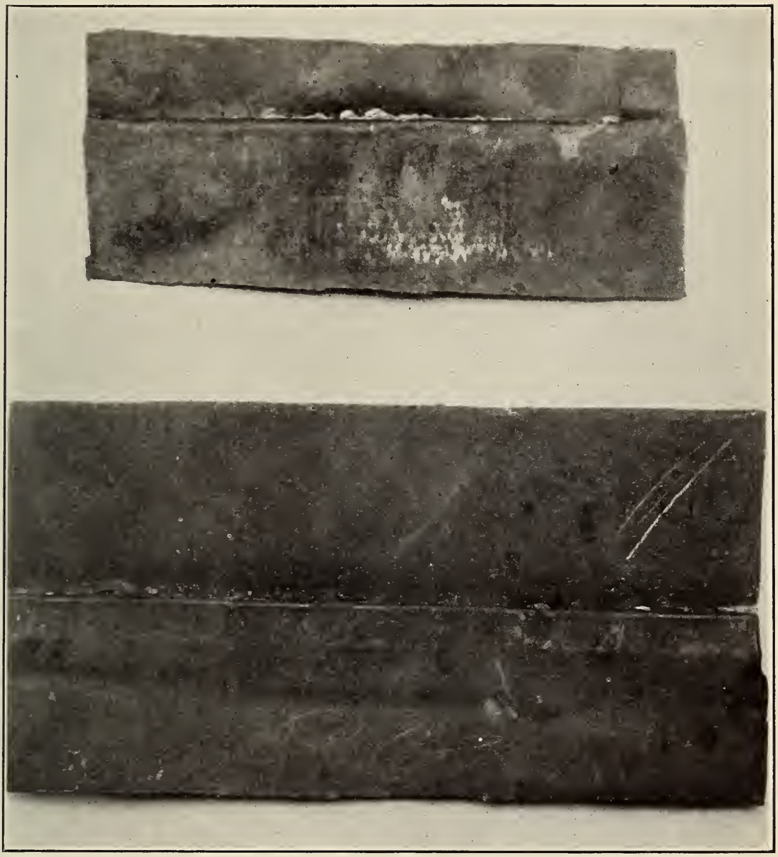

FIGURE 4.—*Sections of a calked seam removed from a building in New York City after many years of service*

Upper piece shows under surface of seam with traces of white lead near center. Lower piece shows upper (exposed) surface of seam.

1. LEAKAGE TESTS

(a) SPECIMENS

Leakage tests were made on two specimens with new seams, and on one old seam.

Two views of specimen No. 1 are shown in Figure 3. It consists of a roof section about 36 inches long by 26 inches wide covered with 16-ounce copper. The seams are half-inch flat lock calked with a white lead paste containing about 8 per cent of linseed oil. The copper was secured by cleats spaced about 9 inches apart. The sheathing under the copper was cut away, as shown at *A* on the upper view in the photograph, to expose the lower surfaces, *S*, of the seams so that any leaks might readily be observed.

Specimen No. 2 was similar in all respects to No. 1, except that the white lead paste contained about 15 per cent of linseed oil.

Specimen No. 3 was a sample selected from a number of pieces of a seam removed from a building in New York City after many years of service. Two pieces of this seam are shown in Figure 4. The smaller piece shows the appearance of the under surface of the seam; traces of the white lead can be seen at the middle of the piece. The larger section shows the upper or exposed surface. Note how inconspicuous the seam is. The sample selected for test was one which appeared to have suffered no injury during removal. The age of the seam and the composition of the white-lead mixture are not known.

Each specimen was mounted in a sheet metal tank, 13 inches deep, so that the specimen formed the bottom of the tank.

(b) TEST PROCEDURE

On the new seams, specimens No. 1 and No. 2, the order of tests was as follows: Leakage test; artificial aging; leakage test; check leakage test. On the old seam (specimen No. 3) one leakage test was made.

In the test for leakage the specimens were first subjected to a head of 1 inch of water for several days. The head was then increased at intervals of several days until leaks appeared or until the head was 12 inches.

The artificial aging process consisted of 57 cycles of alternate heating and cooling. The specimens were placed in a large heating chamber, and each morning were heated for two hours until the temperature in the chamber was about 110° F. above room temperature. The chamber was then opened and cooled to room temperature in about four hours. The specimens were again heated and left in the closed chamber to cool very slowly over night. The average temperature change for each cycle was 110° F. The maximum temperature reached was 220° F. and the minimum 70° F.

(c) RESULTS

The results of the tests are given in Tables 2, 3, and 4. In column 4 of Tables 2 and 3 wherever the rate of leakage is noted as "trace" or "slow," the leaks were so slight that they probably could not have been detected on an ordinary roof with wood sheathing. Leaks listed as "fast" would probably have been evident under similar circumstances, but in no case could they have been described as bad leaks.

Table 2 shows that only two very slight leaks appeared on each of the new specimens in a week under a head of 12 inches. This depth is far greater than any which would ever occur on a properly designed roof. In both cases these leaks were so slight that they could not have been detected in a building. In fact, on specimen No. 1 (8 per cent oil) both leaks soon disappeared and no other appeared after the fourth day.

TABLE 2.—*Leakage tests on new calked seams*

Specimen No. 1. WHITE LEAD WITH 8 PER CENT OF LINSEED OIL

Depth of water (in inches)	Total time under water	Number of leaks	Rate[1]	Location
	Days			
1	7	None.		
2	6	None.		
4	5	None.		
6	4	None.		
9	3	None.		
12	1	None.		
	2	1	Trace	Cleat.
	3	1	do	Seam junction.[2]
	4	None.		
	8	None.		

Specimen No. 2. WHITE LEAD WITH 15 PER CENT OF LINSEED OIL

1	7	None.		
2	6	None.		
4	5	None.		
6	4	None.		
9	3	None.		
12	1	1	Slow	Seam junction.
	2	2	Traces	Seam junctions.
	7	2	do	Do.

[1] Rate of leaking specified as follows: Trace, wet spot on under surface of seam; slow, water dripping at long irregular intervals; fast, water dripping steadily, less than 5-minute intervals.

[2] Seam junction refers to a place where a cross seam connects with a longitudinal seam.

TABLE 3.—*Leakage tests on new calked seams after artificial aging*

Specimen No. 1. WHITE LEAD WITH 8 PER CENT OF LINSEED OIL

Depth of water (in inches)	Total time under water	Number of leaks	Rate[1]	Location
	Days			
1	3	None.		
2	3	None.		
3	3	None.		
4	2	None.		
	3	1	Trace	Cleat.
	4	1	Slow	Do.
	5	1	Trace	Do.

[1] Rate of leaking specified as follows: Trace, wet spot on under surface of seam; slow, water dripping at long irregular intervals; fast, water dripping steadily, less than 5-minute intervals.

TABLE 3.—*Leakage tests on new calked seams after artificial aging*—Continued

SPECIMEN DRIED FOR ONE WEEK AND RETESTED

Depth of water (in inches)	Total time under water	Number of leaks	Rate	Location
	Days			
1	7	None.		
2	5	None.		
3	7	None.		
4	11	None.		
5	[2] 0	1	Slow	Cleat.
	5	1	Trace	Do.
	14	3	Traces	Do.
	18	3	do	Do.
6	4	3	do	Do.
Specimen No. 2. WHITE LEAD WITH 15 PER CENT OF LINSEED OIL				
1	3	None.		
2	[2] 0	1	Trace	Cleat.
	2	2	Traces	Cleats.
	3	3	do	Do.
	5	2	do	Do.
	9	None.		
	11	1	Trace	Cleat.
		1	do	Seam junction.
SPECIMEN DRIED FOR ONE WEEK AND RETESTED				
1	7	None.		
2	2	None.		
	3	1	Trace	Cleat.
	14	1	do	Do.
		1	do	Seam junction.
3	18	1	do	Cleat.
		1	do	Seam junction.
4	3	1	do	Cleat.
		1	do	Seam junction.
	4	4	Traces	Cleats.
		1	Fast	Cleat.

[2] 1 hour.

TABLE 4.—*Leakage test on old weathered calked seam*

SPECIMEN NO. 3

Depth of water (in inches)	Total time under water	Number of leaks	Depth of water (in inches)	Total time under water	Number of leaks
	Days			*Days*	
1	14	None.	5	18	None.
2	5	None.	6	31	None.
3	7	None.	7	31	None.
4	11	None.	12	45	None.

During the tests, some of the white lead leached out of the seams on both specimens Nos. 1 and 2 in the form of a fine, white powder. The relative amounts of the sediment on the two specimens could not be accurately measured, but it was quite evident by inspection that less powder was formed on specimen No. 1. This would indicate a slight superiority of the white-lead paste with 8 per cent of linseed oil.

The only visible effects of the artificial aging process were the discoloration of the white lead, which turned a light yellow color, darkening to brown in patches, and a few very small surface cracks in the white lead. Otherwise the seams appeared to be unchanged, and there was no appreciable buckling or other distortion of the copper sheets.

However, the aging greatly impaired the water-tightness as is evident in Table 3. In the first test after aging, on specimen No. 1, 8 per cent oil, one slight leak appeared under 4 inches of water; and on specimen No. 2, 15 per cent oil, three slight leaks under 2 inches of water. After this test the specimens were dried in the laboratory for one week, and then retested. Specimen No. 1, this time developed only three slight leaks during 18 days under 5 inches of water. These leaks did not increase in four days under 6 inches of water. On specimen No. 2 five leaks developed in four days under 4 inches of water. One of these probably would have been sufficient to penetrate any ordinary roof sheathing. These tests show that the white lead paste with 8 per cent of linseed oil, as used on specimen No. 1, is definitely superior to that with 15 per cent of linseed oil.

It should be noted that all of the leaks occurred either at cleats or at seam junctions; that is, places where the cross and longitudinal seams meet.

The artificial aging can not, of course, be considered as directly comparable with the aging which takes place on a roof. In one respect the test was more severe than actual service conditions for the high temperatures were 50° to 70° F., higher than any which would ever occure on a roof. Nevertheless, even after this severe treatment, the seams calked with white lead paste containing 8 per cent linseed oil were still satisfactory, for only under very extreme conditions would water on a roof be likely to reach a depth of 4 inches.

The tests of the old weathered seam, specimen No. 3, Table 4, were surprising in that no trace of a leak could be detected even after 45 days under a head of 12 inches of water. The results indicate that long service is not likely to impair the water-tightness of calked seams. It is possible, however, that if the specimen had been large enough to include a seam junction or a cleat, some slight leakage might have occurred at these places.

It may be concluded that seams calked with white lead with 8 per cent of linseed oil will give satisfactory service wherever the depth of water standing on the roof for several days will not exceed 4 inches. There is little likelihood that the seams will leak under depths 2 or 3 inches greater, provided the water drains off in a few hours.

V. SOLDERED SEAMS

Soldered seams (fig. 1) are intended for roofs of very slight slope, for gutters, and, in general, for places which may be flooded with water. The soldered flat lock is the more common form, as it permits the use of cleats for fastenings. The lap seam is used where cleats are not needed or where it may be difficult to make a flat lock.

Proper allowance for the effects of temperature changes is more difficult to secure with soldered seams than with other types, as there can be no relative movement in the seams between the adjacent sheets. Adequate roof fastenings, carefully placed, are essential for best results, and special expansion joints are sometimes desirable. The seams themselves must be strong enough to withstand the stresses caused by temperature changes. When failure occurs, it is generally due to insufficient strength of the seams; the solder cracks and the roof begins to leak.

1. TENSILE TESTS

The purpose of the tensile tests was to determine the influence of various factors on the strength of soldered seams. The factors taken into consideration were: (1) The kind of flux; (2) the direction of rolling of the copper, (3) the width of lap seams; (4) the width (amount) of solder on flat-lock seams, and (5) pretinning. The effects of variations in the composition of the solder and in the quality of the workmanship were not studied.

(a) SPECIMENS

The tensile specimens consisted of eight sets such as that given in Table 5.

TABLE 5.—*Set of specimens for tensile tests of soldered seams*

[Two sets of specimens, one with seams parallel and one with seams transverse to the direction of rolling of the copper, were made from each of four gages of copper, namely, 14, 16, 18, and 20 ounces]

LAP SEAMS

Flux	Pretinning	Widths of seam tested	Number of specimens
		Inch	
Resin	None	¼, ½, ¾, 1	16
Acid	do	¼, ½, ¾, 1	16
Prepared	do	¼, ½, ¾, 1	16
Acid	With solder	¾	4
	With tin	¾	4

FLAT-LOCK SEAMS

Flux	Pretinning	Widths of seam tested	Widths of solder[1] tested	Number of specimens
		Inch	*Inches*	
Resin	None	½	½, 1, 2	12
Acid	do	½	½, 1, 2	12
Prepared	do	½	½, 1, 2	12
Acid	With solder	½	1	4
	With tin	½	1	4

Total number of specimens in set, 100.

[1] Width of band of solder showing on finished seam. This width is taken as a measure of the amount of solder used.

The quantities of solder corresponding to the different widths as given in the fourth column of the second part of Table 5 were determined by weighing representative specimens and deducting the estimated weight of the copper. The values thus obtained seemed so low that they were checked by weighing specimens before and after burning off the solder, and also by weighing the solder scraped from specimens. The results, which checked reasonably well, are given in Table 6. There were variations of as much as 50 per cent from specimen to specimen.

TABLE 6.—*Amount of solder on flat-lock seams*

Width of solder band (in inches)	½	1	2
Amount of solder (in ounces per lineal inch of seam)	0.04	0.06	0.21

Sample seams were made in lengths of 8 inches joining sheets of copper about 6 inches wide. The joined sheets were cut into four specimens each 2 inches wide with the seams crossing the middle of the specimens. From these, tensile specimens were prepared with a reduced width of 1¼ inches over a gage length of 4 inches. All soldering was done by the same man under conditions as nearly similar as possible. No laboratory refinements of any sort were used. The work was of uniformly high quality such as would be found on the best of copper roofs.

Pretinning was done as follows: Solder, or tin, was melted in containers of the requisite size heated by gas. The copper sheets were dipped into killed acid flux to a depth of 1½ inches. While still wet with the flux, the sheets were dipped into the molten solder, or tin, quickly removed, wiped clean with a cloth, and then allowed to cool. Temperatures were not measured. This procedure is in accord with shop practice.

All other specimens were tinned with solder flowed on with a soldering copper, just as would be done on a roofing job.

Commercial roofing-temper, soft copper was used. This was electrolytic copper, 99.953 per cent copper by analysis, with no unduly large proportion of any impurity. The solder and tin were purchased in the open market. The solder analyzed 48.8 per cent tin and 50.8 per cent lead; and the tin 99.1 per cent tin.

The acid flux was made up in the usual way from clean zinc scraps and hydrochloric acid. Great care was taken to "kill" the acid thoroughly. Even so, analysis showed 5.2 per cent free hydrochloric acid in the resulting flux. The "prepared" flux was a commercial article containing about 86 per cent zinc chloride and about 12 per cent ammonium chloride.

Eight tensile specimens of 0.75-inch width and 4-inch gage length were prepared from each gage of copper.

(b) TEST PROCEDURE

The tests were made in the usual manner on a 20,000-pound testing machine with a counterpoise giving a range of 5,000 pounds.

(c) RESULTS

The tensile strength of the sheet copper was determined for purposes of comparison. The results are given in Table 7, and are shown by broken lines on the graphs in Figures 5 to 12, inclusive.

TABLE 7.—*Tensile strength of sheet copper*

Gage of sheet (in ounces per square feet)	Nominal thickness	Number of specimens	Average tensile strength	Maximum deviation from average
	Inch		*Lbs./in.²*	*Per cent*
14	0.0189	8	31,300	4.2
16	.0216	8	31,900	1.9
18	.0243	8	32,100	2.2
20	.0270	8	32,200	1.9

1. Flux.—In Figures 5 to 8, inclusive, each graph shows the comparative tensile strengths of specimens made with resin (circles), killed acid (squares), and "prepared" flux (triangles), with seams parallel and transverse to the direction of rolling. The markedly low values of occasional points on the graphs are due to seams with imperfections in soldering, such as bubbles, untinned spots, etc.

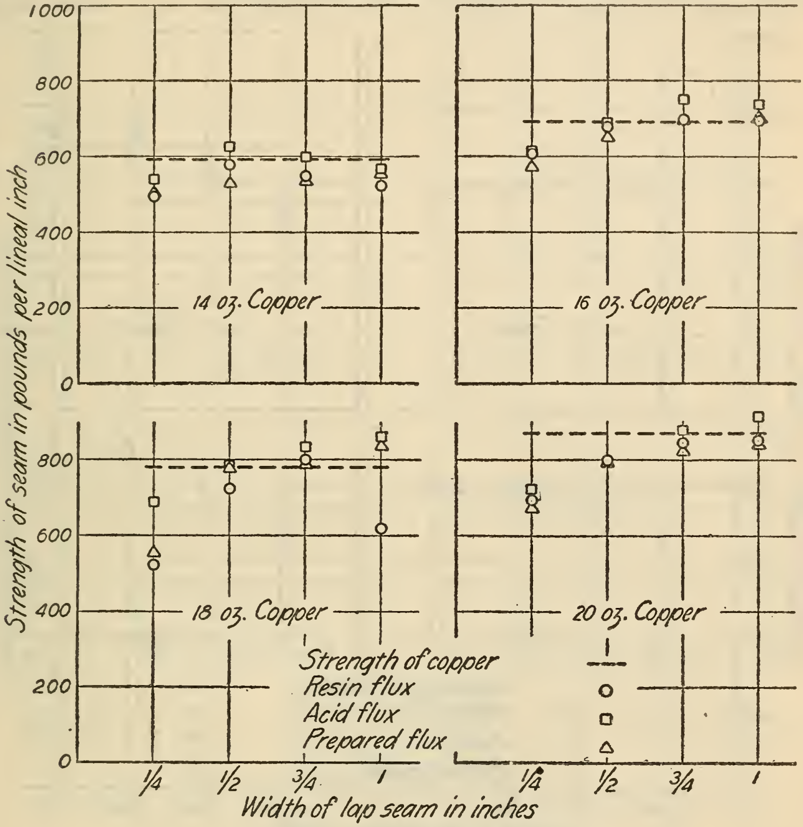

Figure 5.—*Effect of flux on strength of lap seams*

Seams parallel to the direction of rolling of the copper. Each point is an average for four specimens

There are no differences in the tensile strengths of either the lap seams or the flat-lock seams which can be ascribed to the kind of flux used. It should not be assumed, however, on the basis of this conclusion, that all fluxes are equally satisfactory. All traces of flux can not be removed from the seams after a roof is completed. If the flux is corrosive, there is a possibility that corrosion may be started which otherwise would not occur. Since equally strong seams result from the several kinds of flux tried, it is reasonable to infer that the flux which is least corrosive will give the most satisfaction in service.

2. Direction of Rolling.—As no difference in strength depending on the flux was found, the results for all three fluxes on each type and size of seam were averaged. The average values are plotted on the graphs in Figures 9 and 10 to show any relation which might exist between the direction of rolling of the copper and the strength of the seams. It is evident from the graphs that seams parallel and transverse to the direction of rolling are equally strong.

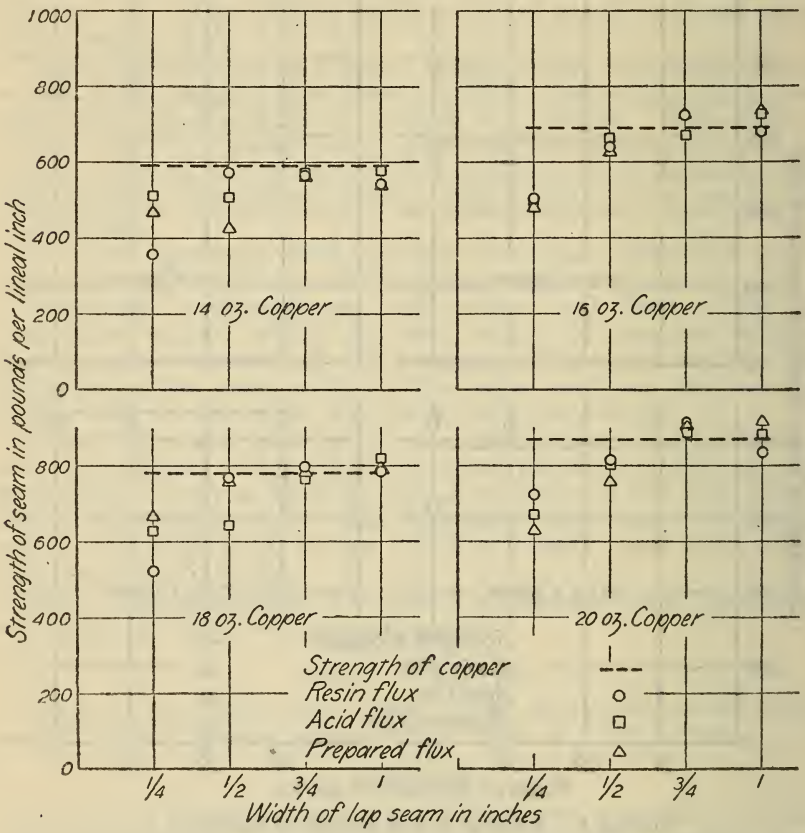

Figure 6.—*Effect of flux on strength of lap seams*

Seams transverse to the direction of rolling of the copper. Each point is an average for four specimens

3. Width of Lap Seams.—In Figure 11 the graphs show the relation between the strength and the width of lap seams. Each point represents the average strength of a given width of seam on one gage of copper, including seams both parallel and transverse to the direction of rolling and made with the three kinds of flux.

Specimens with seams which were not as strong as the copper broke in the seams. The results for these can be closely approximated on each graph by a sloping straight line, showing that the strength of the seams increases in proportion to the increase in width of seam. As nearly as can be judged, the strength increases at the same rate on all thicknesses of copper which were tested.

Above a certain critical width the seam strengths are practically constant, as shown by the continuous horizontal lines on each graph. Some of the specimens of seams at approximately this critical width broke in the seam and others in the sheet copper itself. Seams of greater width (1 inch) nearly all broke in the copper. The results for seams wider than the critical width, therefore, ought to correspond very closely to the results for sheet copper represented by the broken horizontal lines. The graphs show that they do so. The greatest discrepancy occurs on the 14-ounce copper where the maximum strength of the seams is about 7 per cent less than the strength of the copper sheet. On the 16-ounce copper the discrepancy is about 3 per cent and on the other two gages less than 1 per cent, the seam strength being greater than that of the copper in each case. These discrepancies are probably due to variations in the copper sheets.

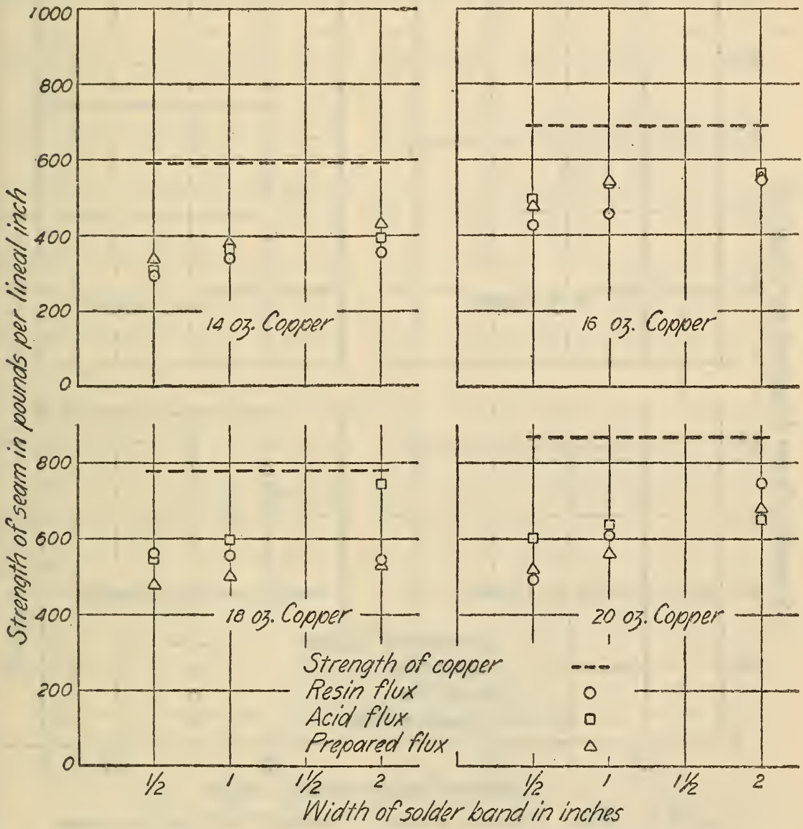

FIGURE 7.—*Effect of flux on strength of one-half inch flat-lock seams*

Seams parallel to the direction of rolling of the copper. Each point is an average for four specimens

It would appear that the critical width, thus determined, would be the width required for roofing seams. This is not the case, as will be brought out later in the discussion of the prolonged loading tests, for the total time during which a seam is under load must also be considered. The results of the tensile tests do show, however, that lap seams less than three-fourths inch wide will under no circumstances be satisfactory for copper roofing.

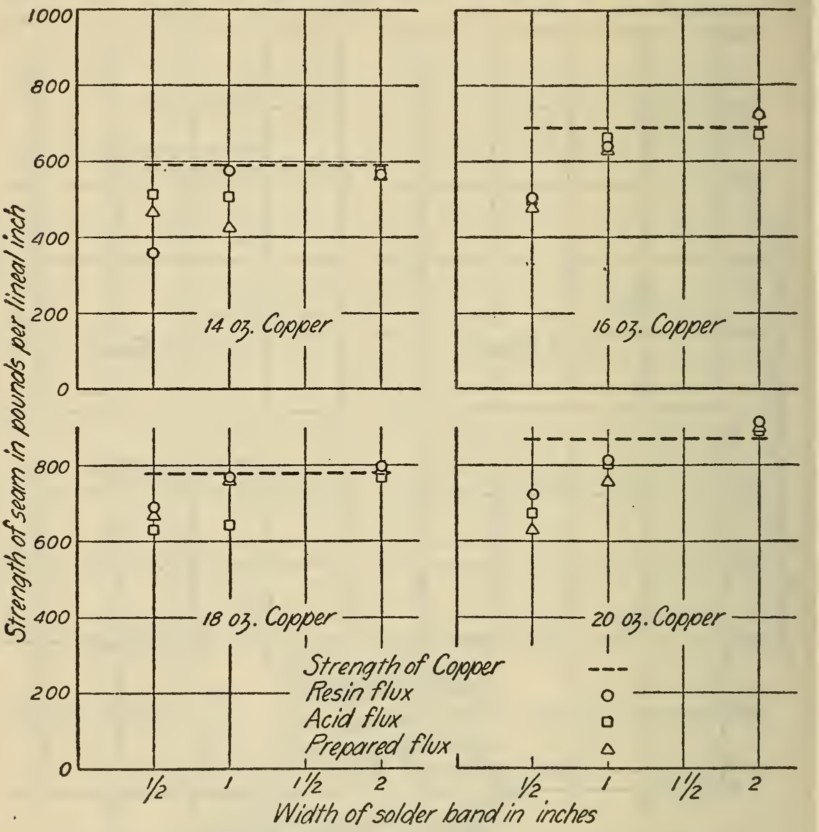

FIGURE 8.—*Effect of flux on strength of one-half inch flat-lock seams*

Seams transverse to the direction of rolling of the copper. Each point is an average for four specimens

4. WIDTH (AMOUNT) OF SOLDER, FLAT-LOCK SEAMS.—In Figure 12 the graphs show the relation between the strength of flat-lock seams and the width of the solder band showing on the finished seams. Note that a large increase in the width of the solder band, corresponding to a great increase in the amount of solder used, results in only a small increase in strength. Also note that even with the greatest widths (largest amounts) of solder, these seams do not

approach the strength of the copper sheets, shown by the horizontal broken lines. Evidently piling up heavy wide bands of solder on flat-lock seams to increase their strength is not worth while. A more efficient method is discussed later in connection with pretinning.

5. PRETINNING.—The strengths of lap and flat-lock seams pretinned with "50–50" solder (half lead, half tin) as compared with those pretinned with tin are shown in the graphs of Figure 13. The pretinning is equally effective whether solder or tin is used.

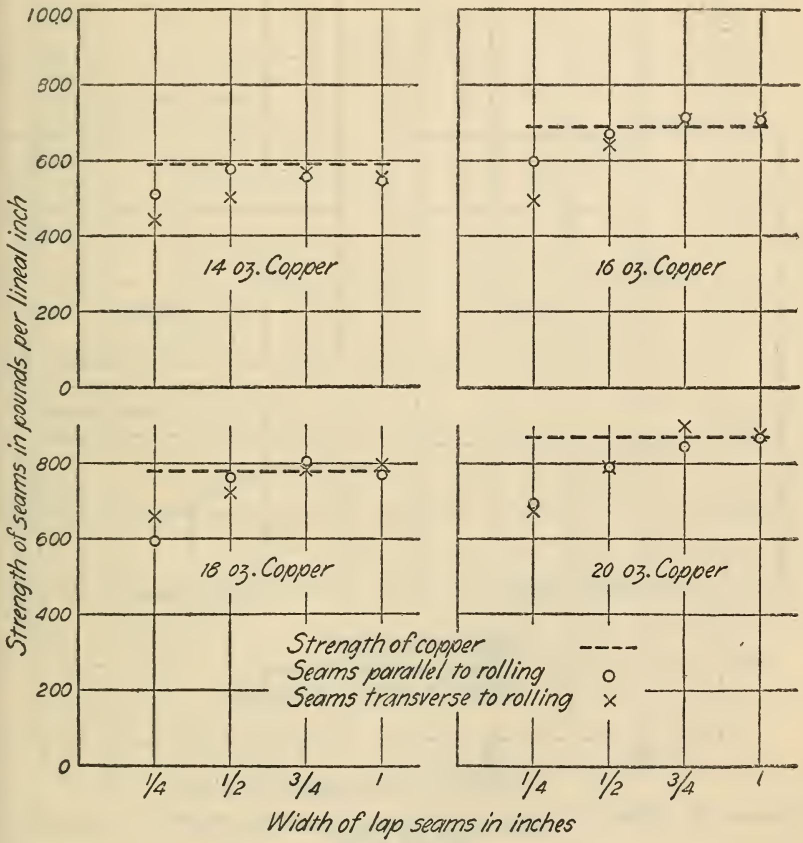

FIGURE 9.—*Effect of direction of rolling of copper on strength of lap seams*

Each point is an average for 12 specimens

As the three-fourths-inch lap seams, whether pretinned or not, are approximately equal in strength to the copper sheets of all gages tested (fig. 11), the effect of pretinning can not be shown graphically. However, 30 per cent of the specimens not pretinned and only 11 per cent of the pretinned specimens failed in the seam, indicating that the pretinning does result in greater strength. The increased strength is due to the greater uniformity and the more thorough union of solder, or tin, to copper obtainable by pretinning.

On the flat-lock seams a very great increase in strength results from pretinning, as shown in Figure 14. With pretinning it is possible to obtain complete union between all the layers of copper in the seam, whereas in the flat-lock seam as ordinarily made without pretinning only two of the layers are completely joined. See Figure 1. There is a decided falling off of the strength of the pretinned seams on the 20-ounce copper. Examination of these specimens disclosed incomplete joining of the solder. In all probability, because of the greater thickness of these seams, enough heat was not supplied by the soldering copper to melt or "flow" the solder.

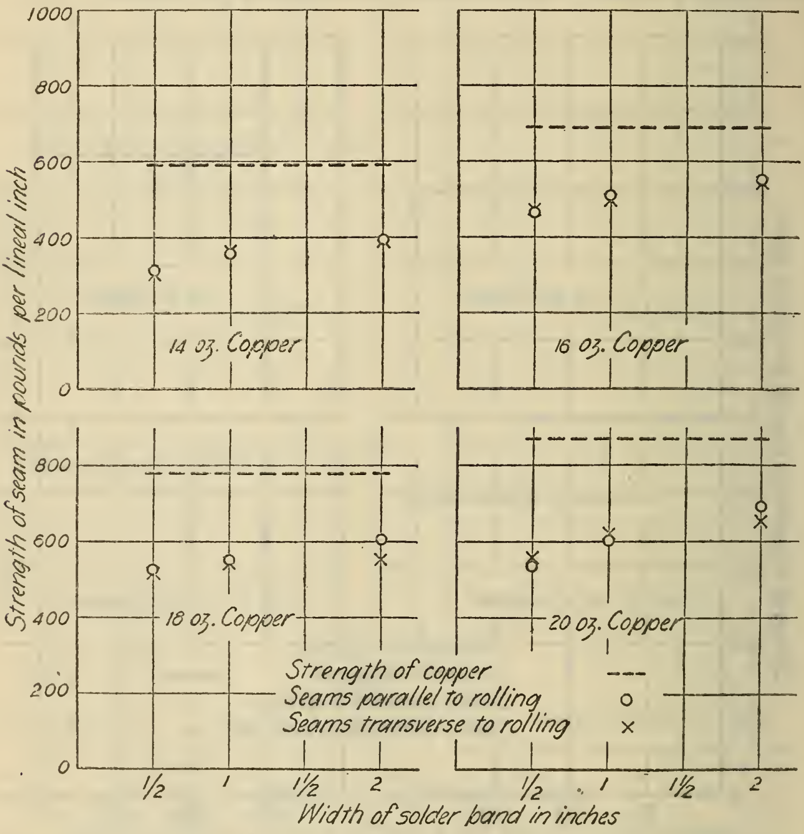

FIGURE 10.—*Effect of direction of rolling of copper on strength of one-half inch flat-lock seams*

Each point is an average for 12 specimens

These results are of great importance as concerns copper roofing. Soldered flat-lock seams are practically always used for flat roofs and gutters, and usually they are not pretinned. These seams probably give more trouble than all other types combined. Pretinning, even if it will not completely solve the problem, very likely will eliminate most of the trouble. The main point is that lock seams which are completely filled with solder are much stronger than those made in any other way.

2. PROLONGED LOADING TESTS

It has been observed that cracks sometimes appear in the solder of seams which have been perfectly satisfactory for one or more years.

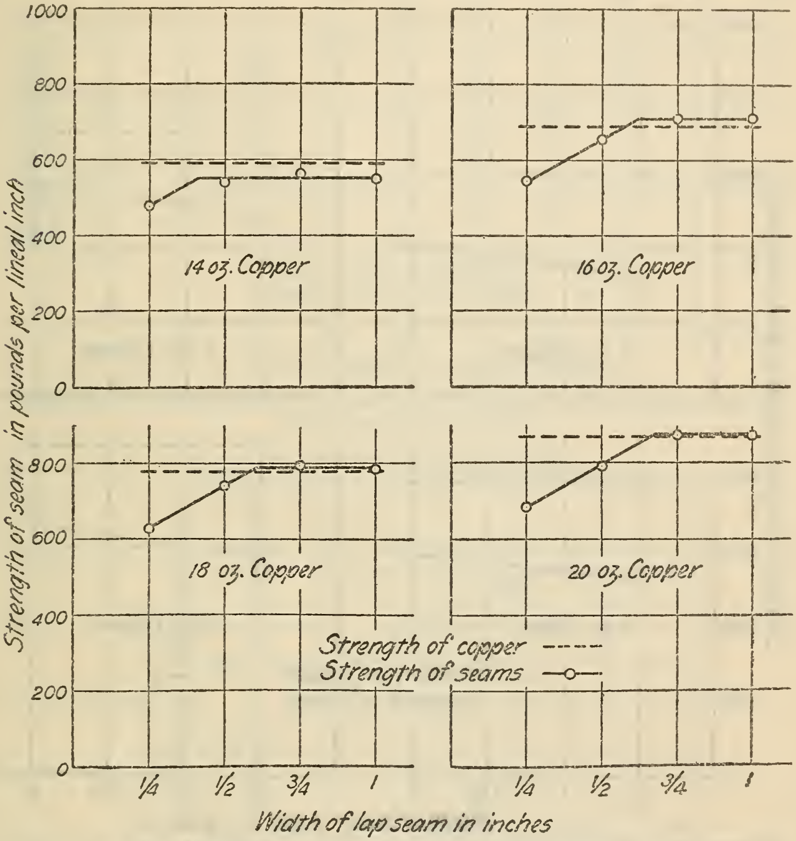

FIGURE 11.—*Effect of width of lap on strength of lap seams*

Each point is an average for 24 specimens

The results of the short-time tensile tests furnish no clue to this behavior of seams. However, it has long been known that solder will flow or "creep" under the continued action of a load not large enough to cause immediate failure. If the load is sufficiently large, the flow will continue until the solder fails. Solder in a joint or seam behaves in a similar manner. Previous work[1] has been concerned with

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[1] See, for example, "Tensile Properties of Soldered Joints under Prolonged Stress," Freeman and Quick, The Metal Ind., N. Y.; January, 1926.

specially prepared specimens not at all representative of seams such as would be found in a copper roof. The tests to be described were undertaken in order to obtain data on seams made according to roofing practice.

(a) SPECIMENS

The specimens consisted of copper strips 2 inches wide and 12 inches long with a transverse seam at the center. For the one-fourth and one-half inch lap seams, the full width specimens were tested. All others were milled down to a width of 1 inch so that smaller test loads could be used. The lap seams were made from the same materials and by the same workman as the tensile-test specimens, previously described. The flat-lock seams were made up especially for these tests. The sheet copper was from the same source as the tensile specimens. The solder was "50–50" lead-tin composition of ordinary market grade. The flat-lock seams were pretinned so that each seam was entirely filled with solder. It was not thought worth while

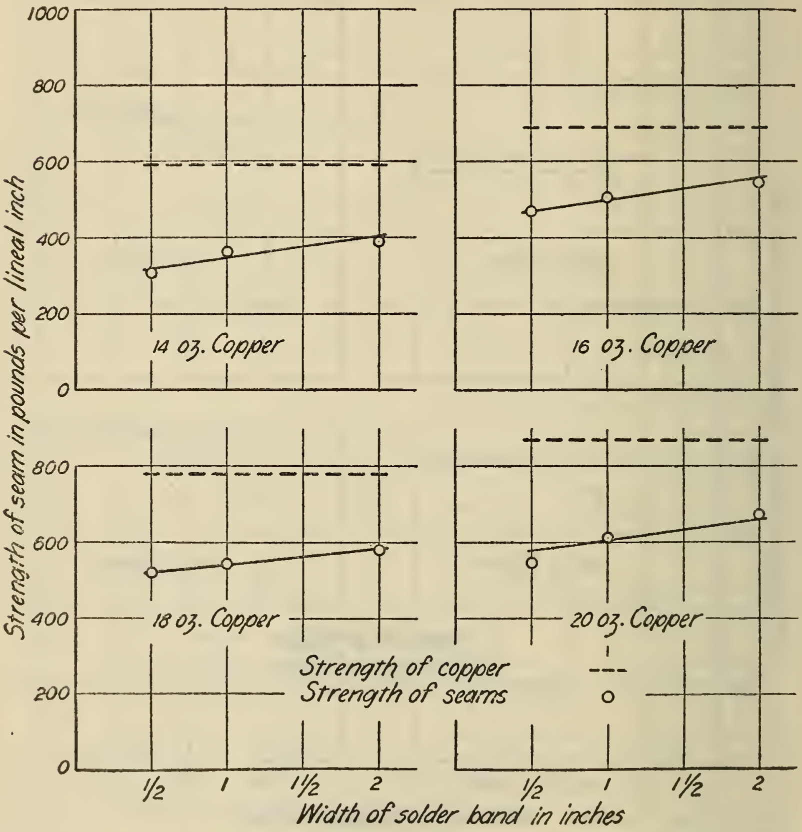

FIGURE 12.—*Effect of width (amount) of solder on the strength of one-half inch flat-lock seams*

Each point is an average for 24 specimens to test flat-lock seams which had not been pretinned, since such seams gave very low strengths in the tensile tests.

(b) TEST PROCEDURE

Figure 15 is a photograph of a seam under test showing the method of suspending and loading the specimen. Each specimen was inspected morning and evening so that the time of failure was determined within half a day. The specimens under very heavy loads were inspected hourly during the first 10 hours.

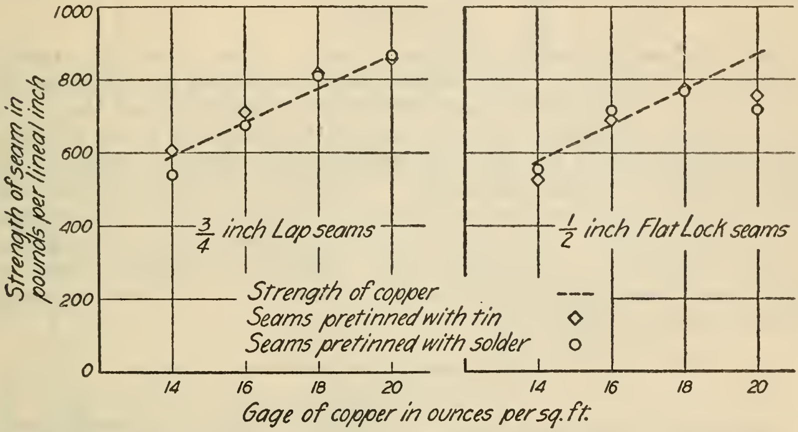

FIGURE 13.—*Comparsion of results of pretinning with tin and with "50–50" (half lead, half tin) solder*

Each point is an average for 8 specimens

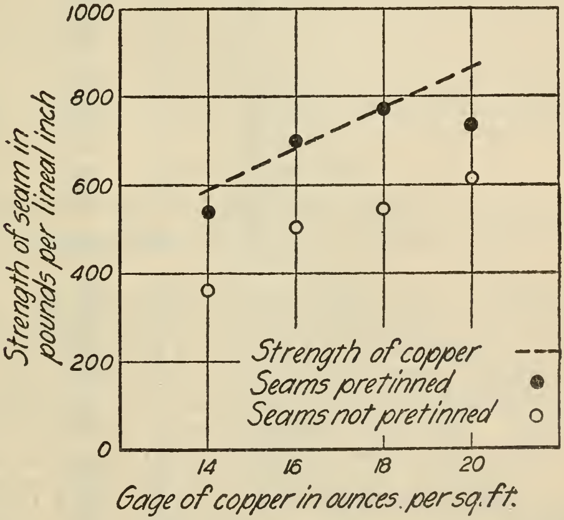

FIGURE 14.—*Effect of pretinning on strength of one-half inch flat-lock seams*

Each point is an average for 16 specimens

"Creep" was not measured. It was observed, however, that failure occurred in a progressive manner. On both types of seams the first indications of failure were fine cracks in the solder along the edges of the seams. These cracks gradually opened and spread toward the center of the seam until finally the solder gave way suddenly. On the lap seams with the heaviest loads this progressive failure took place within a half hour, while on one or two of the flat-lock seams under light loading the initial crack was observed nearly two weeks before the final complete failure.

(c) RESULTS

The results are given in Tables 8 and 9. The "nominal stress," reported in column 3 of the tables, was computed by dividing the total load in pounds by the area of the seam (width times length) in square inches. In the case of lap seams this nominal stress becomes very nearly equal to the shearing stress in the solder as soon as the solder begins to deform plastically. A number of the lap seams were found to have imperfections, such as bubbles in the solder or untinned spots on the copper. The areas which appeared to be well soldered on these seams were measured and "corrected stresses" based on these areas were computed (column 4 in Table 8). In most cases the imperfections were slight.

TABLE 8.—*Prolonged loading tests of soldered lap seams*

Gage of copper (in ounces per square foot)	Width of seam (inches)	Nominal stress [1] (lbs./in. ²)	Corrected stress [2] (lbs./in. ²)	Time to failure (days)
14	¼	1,200		0.2
		1,000		.5
		800		1.5
		700		2.1
		600		3.5
		500		6.0
		450		14.0
		410	630	2.5
		400	460	10.0
		370		86.0
	½	600	620	4.5
		500		13.0
		400		23.0
	¾	500		11.0
		400		26.0
16	¼	600		4.0
		500		10.0
		420	460	15.0
		420		21.0
		400		43.0
		380		26.0
		380		83.0
18	¼	600	680	4.0
		360		63.0
	½	600	620	4.0
		500		15.0
	¾	600	710	4.0
		500		31.0
	1	600	610	2.0
		500		10.0
		400		41.0
20	¼	600		6.0

[1] Total load in pounds divided by area of seam in square inches.

[2] On defective seams, a "corrected stress" was computed as the total load in pounds divided by the area in square inches of that part of the seam which appeared to be well soldered.

TABLE 9.—*Prolonged loading tests of one-half inch soldered flat-lock seams*

Gage of copper (in ounces per square foot)	Nominal stress [1] (lbs./in.^{2})	Time to failure (days)
16	900	0.5
	700	2.0
	600	3.0
	500	25.0
	450	15.0
	400	240.0
	390	231.0

[1] Total load in pounds divided by area of seam in square inches.

The data for the lap seams are plotted on the graph in Figure 16. For defective seams only the corrected values are plotted. (Open characters). No differences in the results due to variations in the gage of the copper from 14-ounce (0.0189 inch) to 20-ounce (0.0270 inch) or due to variations in width from one-quarter to 1 inch can be detected. Note that as the stress is decreased slightly under 400 lbs./in.^{2} of seam, the time required to produce failure increases very rapidly and the curve becomes nearly horizontal. The indications are that the maximum stress which lap seams will withstand indefinitely is in the neighborhood of 350 lbs./in.^{2} of seam.

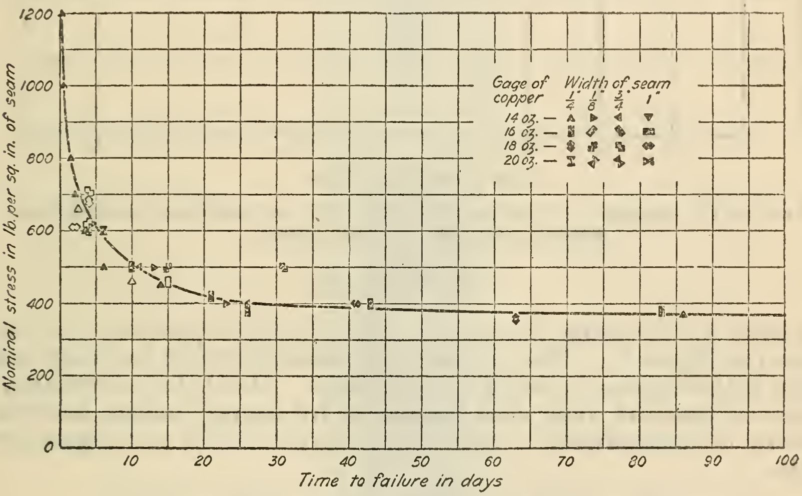

FIGURE 16.—*Results of prolonged loading tests on lap seams*

For seams with imperfect soldering corrected values were computed and then plotted in the diagram as open characters. For these seams only the corrected values were plotted

The graph in Figure 17 gives the results for flat-rock seams. The curve is similar to that for lap seams in Figure 16, but approaches the horizontal at a slightly higher stress. The curve indicates that the maximum stress for which one-half-inch, pretinned, flat-lock seams will withstand for a very long time is about 375 lbs./in.^{2} of seam. Flat-lock seams of other widths were not tested, but very likely these results are applicable to seams of widths up to 1 inch, at least.

The values given above may be used to determine the width of seam required if the load on the seam is known. However, a liberal factor of safety should always be used because it is not possible to determine by inspection whether or not there are any small imperfections in the soldering.

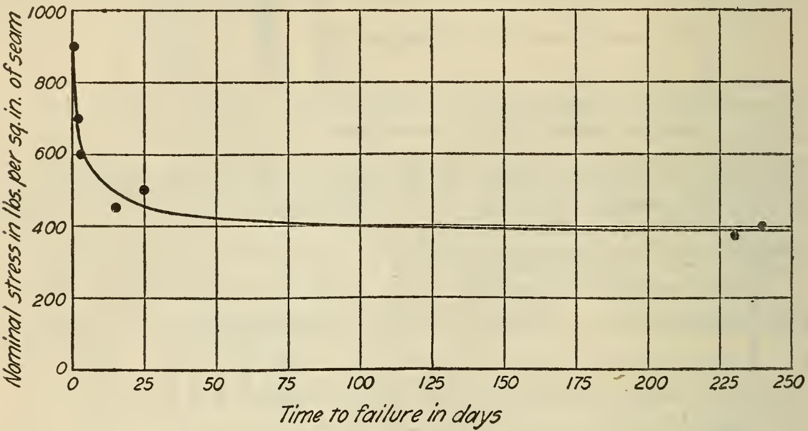

Figure 17.—*Results of prolonged loading tests on pretinned one-half-inch flat-lock seams on 16-ounce copper*

VI. CLEATS

Cleats for fastening the copper sheets to the supporting roof are shown in Figure 18. The narrow cleat, sometimes with two nails and often with only one, is very frequently used. It is believed by many, however, that the wider cleat is superior for copper roofing, and this opinion is substantiated to some extent by the results of comparative tests.

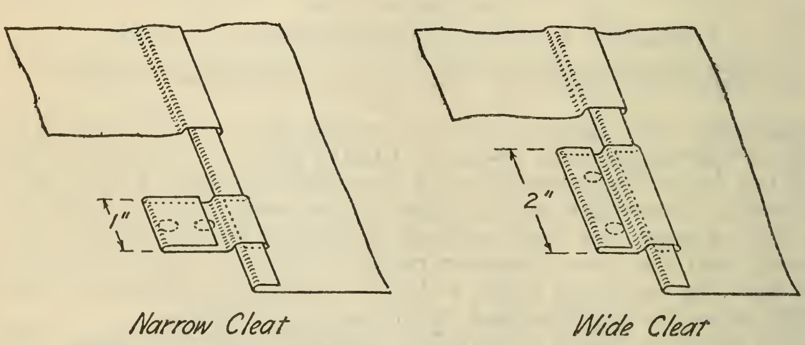

Figure 18.—*Cleats for fastening copper sheets to roof sheathing*

During the course of some expansion tests on a molded copper gutter 50 feet long, several methods of fastening the gutter were studied. Continuous measurements of copper roof temperatures at Washington, D. C., over the period of one year indicated that the maximum range of temperatures ever likely to occur in Washington is approximately from −20° to +160°F. The temperature range

FIGURE 15.—*Prolonged loading test on pretinned ½-inch flat-lock seam*

Seam is indicated by the arrows.

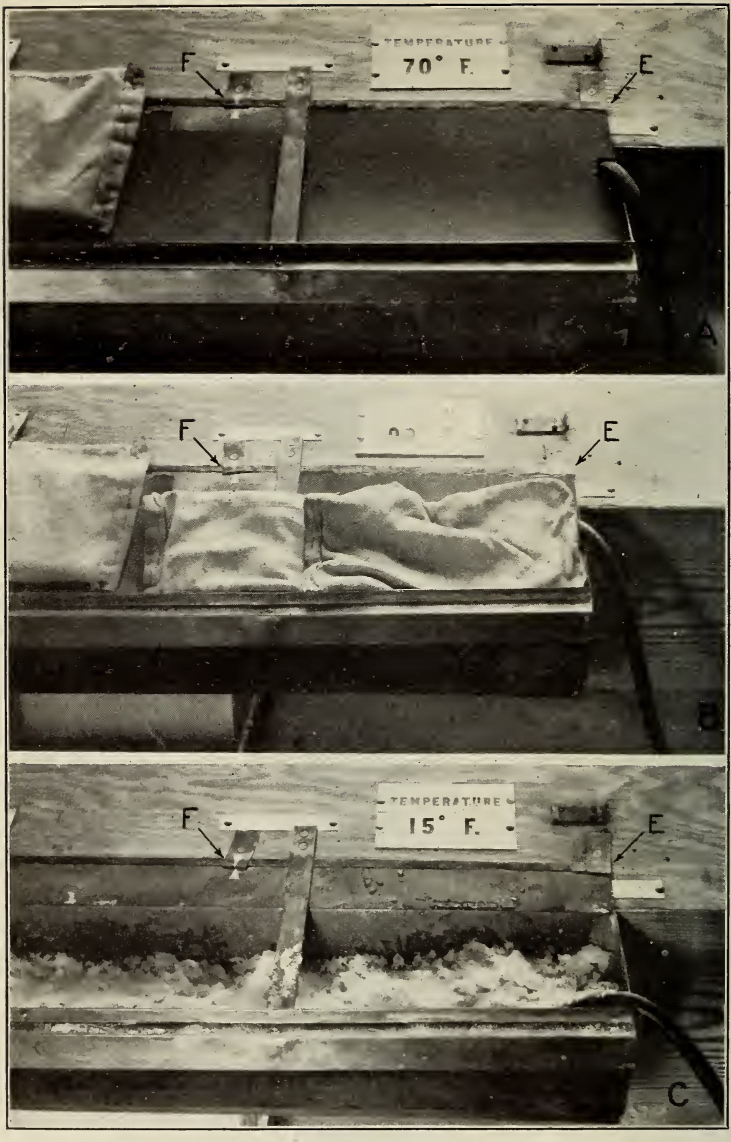

Figure 19.—*Tests on copper gutter fastened to sheathing with narrow cleats, one nail in each cleat*

A, Gutter at temperature of 70° F. ready for tests. Note relative positions of cleats and gutter at *E* and *F*. *B*, gutter at 200° F. Note that cleats at *E* and *F* have been displaced as gutter expanded toward the right. *C*, gutter at 15° F. Note displacement of cleats at *E* and *F* toward left due to contraction of gutter. (The pieces of fiber board and the sand bags shown in photographs *A* and *B* were used for preventing the loss of the steam which was employed for heating. Steam was supplied through a perforated pipe lying in the bottom of the gutter. Sand bags were also used to equalize the load supported by the gutter, the load being maintained practically constant throughout the test.)

of the tests was about the same in extent, but for convenience was raised 35° or 40° F.

Figure 19, *A*, shows the end of the copper gutter mounted for test at a temperature of 70° F. Note that the edge of the end cleat, at *E*, is flush with the end of the gutter, and the painted marker on the second cleat from the end, at *F*, points directly to the marker painted on the gutter itself. Figure 19, *B*, shows the gutter heated by steam to a temperature of about 200° F. The end of the gutter (*E*) has moved one-quarter inch or more toward the right. (The other end moved an equal distance toward the left.) As the gutter expanded, the friction between the cleats and the gutter was great enough to displace the cleats, as shown in the photograph. Note particularly how the marker on the second cleat at *F* points diagonally toward the right. Similar movements, in the opposite direction, took place when the gutter was cooled to 15° F. by means of cracked ice and salt. See Figure 19, *C*, at *E* and *F*. It is obvious that any continued action such as this, even if less pronounced, would eventually result in damage to the cleat, probably by tearing at the nail. When cleats of the same dimensions, but with a second nail placed an inch beyond the first in the center-line of the cleat were tested, their displacement as the gutter expanded and contracted was much less pronounced. However, slight wrinkles could be seen, particularly around the nails nearest the edge of the gutter, which indicated that the cleats were overstressed.

Similar tests were also made on wide cleats such as shown in Figure 18. No displacement or distortion of these cleats could be detected at any time during the tests.

It seems reasonable to infer, therefore, on the basis of these results that the wider cleats will give better service on seams with open locks, such as the ribbed, standing, and open double and single lock seams.

VII. SUMMARY

The following conclusions are based on the results of tests of seams for copper roofing:

1. Flat-lock seams calked with white lead and linseed oil can be used wherever the depth of water which may be standing for several days on the roof will not exceed 4 inches. Such conditions are rarely encountered on copper roofs. The tests indicate that many years of service will not impair the weather-proof qualities of these seams. A mixture of white lead with 8 per cent of linseed oil is superior to one with 15 per cent of oil.
2. Soldered seams were equally strong whether made with resin, acid, or a "prepared" commercial flux. The least corrosive flux should give the best results in the long run, since all appear to be equally satisfactory as regards strength.
3. Soldered seams made parallel or transverse to the direction of rolling of the copper were equally strong.
4. The strength of soldered lap seams, one-quarter to 1 inch in width, is proportional to their widths. The tensile tests showed that lap seams under three-quarter inch in width are not adequate for copper roofing. The proper width can not be determined from the usual tensile test, since it is necessary to take time under load into account.

5. A large increase in the amount of solder used on one-half-inch flat-lock seams results in only a small increase in strength.

6. Pretinning by dipping the edges of the sheets to be joined in molten solder or tin increases the strength of lap and flat-lock seams. The increase is very marked in the case of flat-lock seams since by this method it is possible to join all the layers of copper in the seam.

7. The maximum safe load for soldered lap seams is approximately 350 lbs./in.^{2} (length times width) of seam, and for one-half inch pretinned flat lock seams 375 lbs./in.^{2} of seam. Under greater loads failure will occur after a time, depending upon the magnitude of the load.

8. Cleats 2 inches wide are preferable to those only 1 inch wide.

WASHINGTON, May 7, 1930.