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DEVELOPMENT OF A METHOD
FOR MEASUREMENT OF INTERNAL
STRESS IN BRASS TUBING

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DEVELOPMENT OF A METHOD FOR MEASUREMENT OF INTERNAL STRESS IN BRASS TUBING.¹

By Robert J. Anderson and Everett G. Fahlman.

ABSTRACT.

The investigation discussed in this paper was carried out at the Pittsburgh Experimental Station of the Bureau of Mines in connection with related metallurgical studies on brass. However, since the nature of this phase of the work falls within the province of the Bureau of Standards, by special arrangement it is reported here rather than as a publication of the Bureau of Mines.

A new method for the quantitative estimation of longitudinal internal stress in tube shapes; for example, cold-drawn brass tubes; showed that the major stress is longitudinal, and the stress in the outer part of the wall of the tubing is a longitudinal tensile stress, while that in the inner portion is a longitudinal compressive stress. The summation of the balanced stresses, of course, is zero. Absence of circumferential stress in tubes is indicated by the failure of diametrically cut rings to spring in or out on being slit in two. Experiments showed that the usual cutting methods which have been applied to bars and rods for the estimation of stress are not applicable to tubes, especially where the bulk of the stress is longitudinal.

The method described in the paper for measuring longitudinal internal stress is called the strip method, and is carried out by slitting a narrow strip longitudinally in a piece of tubing; for example, a strip 2.75 inches long and 0.10 inch wide in a 3.25-inch tube length; and then releasing one end of such a slit strip by cutting. Stress is indicated by the springing out of the freed end and can be calculated by a formula based upon the modulus of elasticity of the material and the distance in movement of the freed end.

The method is useful for determining the amount of internal stress in cold-drawn tubes, and for examining quantitatively the effect of a low-temperature anneal upon stress release. It has often been thought that because cold-drawn brass does not crack on application of an accelerating cracking agent it is free from internal stress. The strip method is applicable for the quantitative estimation of stresses inferior to those necessary for cracking under the application of mercurous nitrate.

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¹ Transmitted by the director of the Bureau of Mines.

I. INTRODUCTION.

During the course of an investigation, carried out recently in the Bureau of Mines, dealing with the effect of heat treatment on stress release and on the physical properties of cold-worked leaded brass tubing, a simple method for the quantitative estimation of internal stress in tubing was developed. In carrying out experimental heat treatment work on the release of stress in cold-worked tubes, it was found necessary to have some method for measuring the original amount of stress and the residual stress following heat treatment. An account of the experimental work performed on the effect of heat at moderate temperatures on stress release will be given in a later publication. This method, or an equivalent one, for the detection and measurement of a stressed condition in drawn tubes is new, and a discussion of the subject, therefore, seems fully warranted. The question of internal strains in brass tubing is of considerable interest to brass fabricators and to users of condenser tubes, and it may also be of interest to engineers in general.

Methods for the quantitative determination of internal stress in wrought shapes of brass and other copper alloys have been described at length by other investigators, but these methods were not found to be applicable to the tubing examined by the present authors. No attempt will be made here to outline the various methods suggested or actually used for stress estimation, but it is advisable to indicate the underlying principles involved in them. Thus, Heyn,² described a method for the measurement of internal stress in cold-worked bars which is the most accurate so far devised. Measurement is made of the length of a bar after turning off concentric layers in a lathe. Calculation of the internal stress in each layer removed may be made from the resulting change in length and Young's modulus of elasticity of the alloy. This method is effective for analyzing stress distribution throughout a worked bar. A modification of the method consists in boring out successive concentric longitudinal cylinders and measuring the changes in length. Merica and Woodward³ have given a complete description of the methods employed for measuring internal stress.

² Heyn, E., International strains in cold-wrought metals and some troubles caused thereby, *Jour. Inst. of Metals* 12, pp. 3-37; 1914.

³ Merica, P. D., and Woodward, R. W., Failure of Brass. 1.—Microstructure and Initial Stress in Wrought Brasses of the Type 60 Per Cent Copper and 40 Per Cent Zinc, *B. S. Tech. Paper No. 82*, Jan. 29, 1917.

Hatfield and Thirkell⁴ have developed an ingenious formula for calculating the internal stresses in cups or other articles of similar shape. The method devised by these investigators is based on the fact that when diametral rings are cut off from cups or bowls and then split in two, they open out to a larger curvature. It must be recognized that the calculation of stresses, by cutting a wrought metal object and measuring any dimensional changes or movements gives results which can not be regarded as especially accurate for the reason that the actual stress distribution is invariably complex, and the calculations based on the several methods in use require the assumption of a simple distribution of stress.

Numerous investigators have demonstrated qualitatively the presence of internal stress in brass tubes and other wrought shapes, by the cracking of the material when treated with an accelerating cracking agent; for example, a mercury-salt solution or ammonia. Several investigators, and notably Moore and his collaborators,⁵ recently have demonstrated the release of stress in wrought brass on heat treatment by the failure to crack on treating with an accelerating cracking agent. It might be inferred, as was pointed out by Rosenhain in discussing the work of Moore and Beckinsale, that because a sample of wrought brass does not crack on application of an accelerating cracking agent there are no internal strains present. This assumption is certainly open to proof, and, as a matter of fact, there is experimental proof that strains can exist in tubing that does not crack under the mercurous-nitrate test.

The various methods used, or suggested as applicable to stress detection, were tried by the writers for the examination of leaded brass tubing, where the range of reduction in area by cold work was 17 to 56 per cent, but the presence of stress was not revealed. The tubing was what is known in the brass trade as "leaded 2 to 1 mixture," of the nominal composition 66.33 : 33.17 : 0.5 Cu-Zn-Pb. It was known to be internally stressed because of warping, which occurred on maturing at the ordinary temperature. Since it was necessary to have a measure of the amount of stress release on heat treatment other than one of those already developed the question of the nature of the stresses in these drawn tubes was taken under consideration with a view to the development

⁴ Hatfield, W. H., and Thirkell, G. L., *Season Cracking*, Jour. Inst. of Metals, 22, pp. 67-91; 1919.

⁵ Moore, H., and Beckinsale, S., *The prevention of season cracking in brass by the removal of internal stress*, Jour. Inst. of Metals, 17, pp. 162-192; 1921; and a series of related papers in the same journal.

of a suitable method. This method, described below, referred to hereafter as the "strip method," was found to be especially applicable to this tubing as a means for detecting the presence of such a stressed condition and for measuring stress quantitatively.

II. NATURE OF THE STRESS IN DRAWN TUBING.

The development of the strip method was carried out on tubes which had drawn with an internal mandrel, the material being reduced both as to internal and external diameter on the temper draft. There seems to be no reason, however, why the method can not be applied to hollow-sunk tubes. It has been indicated by certain British investigators that if high internal stresses are to be induced in tubes, it is preferable to draw them by hollow sinking. So far as is known, however, no data have been presented as to the amount of stress in tubes drawn either with an internal supporting mandrel or hollow sunk. Before discussing the method developed in this investigation for the measurement of stress, it is of importance first to consider the kind and character of the stresses under discussion.

In the lots of tubing examined, machining tests made by Heyn's method and by that of Hatfield and Thirkell, as well as treatment with accelerating corroding agents, failed to disclose any evidence of stress, but the behavior of the tubes on maturing at the ordinary temperature made it evident that a stressed condition existed.

Samples of cold-worked tubing, which had been reduced in area 16.8, 22.4, 27.2, 35.4, and 55.9 per cent by cold deformation, were treated by the accelerating mercurous-nitrate test. No cracks were developed on standing, after treatment, for seven months in the case of the material reduced 22.4 per cent. Further, no cracks were developed in the case of the other samples after standing for 30 days. Ammonia and an ammonia-saturated atmosphere were used also, but no cracks developed in any of the samples up to two months standing in air after treatment.

A number of machining tests were carried out by Heyn's method, but no length changes could be found after removing layers from either the inside or the outside of the tubes. In some tests a layer was removed first from the external surface, followed by removal of a layer from the inside, and in others the reverse procedure was followed. No length changes were observed, however.

The machining test suggested by Hatfield and Thirkell was not found to be applicable to the tubing, but a modified form of it was devised. A piece of tubing was slit halfway around the circumference in three places as shown in Figure 1, so as to test the entire circumference for stress. One end of each of the slit strips was set free by cutting. No springing out or movement in any direction occurred, thus indicating absence of circumferential stress. This modification of the diametral ring method of Hatfield and Thirkell is possibly more accurate than their original method since it prevents possible distortion in the sample on cutting.

It is of interest at the outset to consider the views of other investigators as to the nature of stresses in cold-drawn tubes. A number of workers hold that the major stresses are circumferential in character. The authors do not believe that this holds true in all cases, but have found that the principal stresses may be longitudinal. Internal stresses in worked objects in alloys are associated with the deformation caused by the work, and roughly it might be assumed that the drawn tubing used in the development of the strip method was under initial stress induced by the cold working, since the tubes were reduced cold in the range 17 to 56 per cent. It may be pointed out that drawn tubing is stressed differentially; that is, there are strain gradients in such material. It has been argued by other investigators that the internal stresses are circumferential because the tubes split with longitudinal cracks on season cracking or on treatment with an accelerating cracking agent, but they do not seem to recognize that longitudinal stresses of considerable magnitude may be present.

Rosenhain,⁶ says in this connection, "Perhaps a simpler way of looking at the question of internal stress is to think of a flat strip of metal which is initially free from internal stress of any kind. Such a strip can be bent into a U-shape and then, if the opposite ends of the U are clasped together by means of a clip or spring, a definite tension is produced in that fastening. If, instead of such a fastening being employed, the strip of metal is bent into a circular shape, with the two ends close to one another, there is still a tensile stress at the point of junction. A strip bent in this manner is nothing more or less than a short section of tube, and the precise manner in which it is brought into that shape

⁶ Rosenhain, W., The failure of metals under internal and prolonged stress, *Trans. Faraday Soc.*, 17, pp. 2-16; 1921.

has very little effect upon the stresses present in it. It will be seen, therefore, that in any cold-worked tube; that is to say, in any piece of metal which has been brought into a tube shape by deformation in the cold, there must be a circumferential tensile stress." In an analogous manner, Rosenhain goes on to argue that circumferential stresses are also present in cup shapes and in cartridge cases.

Vaudrey and Ballard ⁷ have discussed internal stresses in 70 : 30 brass tubes and state that the stresses are circumferential in character since the failure is in a longitudinal direction on treatment with an accelerating cracking agent (mercurous nitrate). They indicate, however, that longitudinal stress may be present, but that it is not the major one. Moore and Beckinsale ⁸ indicate that both longitudinal and circumferential stresses are present in tubes, but they do not deal with the question in detail.

Merica and Woodward ⁹ have stated that in drawing a tube through a die "the stress caused by the pressure of the plunger or the pull of the tongs is unequally distributed across the section immediately under the die; the portion of the metal just emerging from the die and in immediate contact with it carries more of the load per unit section than the central portion. This inequality of stress distribution persists upon removal of the pulling load or plunging pressure, leaving the outer layers of the tube in tension; the inner, in compression, parallel to the direction of the draw." This indicates longitudinal, tensile, and compressive stresses in drawn tubing, which is confirmed by the present authors, for the type of tubing which they examined.

As stated above, no evidence of circumferential stress was found in tubes drawn with an internal mandrel, which were examined by the writers, on cutting diametral rings. If springing out or in on slitting diametral-cut rings, according to the method of Hatfield, and Thirkell, or a modification thereof, indicates the presence of circumferential stress, it should follow that failure to so spring is an indication of the absence of such stress.

Evidently a great deal is still to be learned about the nature of stresses in drawn tubes. In the case of two other lots of tubing, it was found that the greater stress was longitudinal; one of the

⁷ Vaudrey, R. H. N., and Ballard, W. E., Internal stresses in brass tubes, *Trans. Faraday Soc.*, **17**, pp. 52-57; 1921.

⁸ Moore, H., and Beckinsale, S., Further studies in season cracking and its prevention. *Condenser Tubes Jour. Inst. of Metals*, **27**, p. 149, No. 1; 1922.

⁹ Merica, P. D., and Woodward, R. W., Initial stress and corrosion cracking, *Proc. Am. Soc. for Test. Mats.*, **18**, Part II, pp. 165-178; 1918.

FIG. 1.—*Method of cutting diametral rings in tubing for observation of circumferential stress.*

Actual size.

FIG. 2.—*Illustration of the strip method for internal stress measurement.*

Actual size.

lots had a large amount of circumferential stress and the other only a moderate amount, but in both cases the circumferential stress was readily measurable by the method of Hatfield and Thirkell. These lots of tubing were examined after the major portion of the work described in this article was completed.

On the basis of various tests on the tubing investigated, many of which can not be given here, it is believed that the major stress is longitudinal; that the stress in the outer portion of the tubing is a longitudinal tensile stress; and that the stress in the inner portion of the tubing is a longitudinal compressive stress, the summation of the stresses being zero. On cutting a strip, as in the strip method, the springing out is caused by the combined action of the longitudinal tensile stress which causes shortening of the released strip and by the longitudinal compressive stress which causes lengthening. The foregoing states the case in its simplest terms, but actually the stresses are more complex than those indicated.

III. STRIP METHOD FOR THE DETECTION AND MEASUREMENT OF INTERNAL STRESS.

Upon failure to find any visible evidence of internal stress in drawn tubing in the case of certain lots examined, by the corroding or machining tests described above, the method called the "strip method" was devised, which is applicable to cold-drawn tubes in general. The rationale of carrying out this method based on the assumption that at least part, if not all, of the initial stresses in drawn tubes are longitudinal, tensile, and compressive stresses as already discussed, is as follows: If a narrow strip is slit longitudinally in a piece of tubing; that is, a strip 2.75 inches long and 0.10 inch wide in a 3.25-inch length, as shown in Figure 2, longitudinal stress is indicated by the springing of the strip.

In cutting a strip, the sample of tubing was mounted in a milling machine, and two narrow, parallel cuts were made with a thin cutter; a third cut was then run at right angles to the first two cuts. This cut released one end of the strip and the displacement or springing out of the free end is an indication of the initial internal stress in the tube sample. By using this method, the presence of stress can be detected visually and the amount of stress can be calculated by the formula below. The development of the formula may be explained conveniently by reference to Figures 3 and 4.

FG Figure 3, is taken as the neutral surface of the sprung strip, aa' and bb' are normal sections of the sprung strip, O is the center of curvature, the curve being the arc of a circle if the drawing of the tube is uniform. The distance of the center of curvature from the strip; that is, the radius of the curvature is large, cc' is a line drawn through F parallel to aa' ,

FIG. 3.—Diagram of sprung strip used for development of formula.

cb is the elongation of the fiber ab ,
 $c'b'$ is the diminution of the fiber $a'b'$.

let

$$cb = e,$$

S = the unit stress on fiber ab ,

l = the length of the sprung strip,

$$dl = FG.$$

Then, if

E = the modulus of elasticity of the material,

$$e = \frac{S}{E} dl.$$

Let

g = the distance from b to the neutral surface, and

r = the radius of curvature of the strip.

Then, for a small length dl , there arises two similar triangles GOF and cFb .

Therefore,

$$\frac{OF}{GF} = \frac{Fb}{cb}$$

or

$$\frac{r}{dl} = \frac{g}{e}$$

Since,

$$e = \frac{S}{E} dl$$

Therefore,

$$\frac{r}{dl} = \frac{gE}{Sdl}$$

or

$$S = \frac{gE}{r}$$

Let

t = the thickness of the strip in inches.

Now

$$g = \frac{1}{2} t, \text{ so that}$$

$$S = \frac{tE}{2r} \quad (1)$$

FIG. 4.—Diagram used in development of formula.

In Figure 4, the two radii $o1$ and $o2$ are drawn as shown, and the tangents 13 and 24 are drawn to these radii. The

chord is drawn between the points of tangency 1 and 2, and the line 2 3 is erected perpendicular to the chord at 2. The two isosceles triangles rlk and min are similar, and, therefore,

$$\frac{r}{l} = \frac{m}{i}$$

or

$$r = \frac{lm}{i}$$

But, for small angles

l = the arc 1 2, and

$m = \frac{1}{2}$ the arc 1 2, or

$m = \frac{1}{2} l$.

Therefore,

$r = \frac{l^2}{2i}$, where i is the amount of spring in the strip; that is, the amount it rises above the surface of the tubing on being released at one end.

But since

$$S = \frac{tE}{2r}, \text{ by equation 1,}$$

It follows, on eliminating r , that

$$S = \frac{tEi}{l^2}. \quad (2)$$

This equation is the one employed for calculating internal stress in tubing by the strip method.

IV. RESULTS OBTAINED IN MEASUREMENTS IN TUBES.

By use of the strip method for measuring the amount of internal stress, the stress initially present in cold-worked tubes can be determined, and the effect of heat treatment on its release can be demonstrated visually and quantitatively. Some figures are given below illustrating the latter. The visual effect of heat treatment on stress release as indicated by the strip method is illustrated in Figure 5, which shows three pieces of cold-worked leaded brass tubing (reduction in area, 22.4 per cent) each with a longitudinal strip cut in. The springing out of the strips indicates longitudinal internal stress. Figure 6 shows the same three tubes with strips cut on the opposite sides after heating for various times and at different temperatures; tube 1 was heated for eight

FIG. 5.—Three specimens of cold-worked tubing, showing internal stress by longitudinal cut strips.

Actual size.

FIG. 6.—Effect of heat treatment on internal stress (compare fig. 5).

Actual size.

hours at 275° C., tube 2, five hours at 300° C., and tube 3, two hours at 325° C. The amount of spring, as indicated on the right-hand sides of the tubes in Figure 6, was substantially less after the heat treatments than in the original tubes, as can be seen from the photographs. It is of interest in passing to point out that after heating, the original strips (fig. 5; also shown on the left-hand sides of the tubes in fig. 6) spring out farther, as contrasted with the decrease in the amount of spring shown by the strips cut on the opposite sides.

The springing out of a cut strip may be measured by micrometer, but preferably by micrometer microscope, such as a microscope for taking Brinell-ball-impression readings, and the internal stress calculated from the formula developed above.

$$S = \frac{tEi}{l^2}.$$

The data for one sample tested were as follows:

$$t = 0.057 \text{ inch,}$$

$$E = 13,000,000 \text{ lbs./in.}^2 \text{ the determined elastic modulus of the brass tubing in question,}$$

$$i = 0.086 \text{ inch, and}$$

$$l = 2.75 \text{ inch.}$$

Then,

$$S = \frac{0.057 \times 13,000,000 \times 0.086}{(2.75)^2}, \text{ or}$$

$$S = 8,425 \text{ lbs./in.}^2$$

The question as to the experimental error in stress determinations from measurements of the kind described may be raised. The maximum error in the measurement of wall thickness of tubes should not be more than 0.001 inch, that in the measurement of springing out practically nil, but certainly not more than 0.001 inch, and that in the length of the cut strip not more than 0.005 inch. Assuming a measurement of 0.001 inch too small in the wall thickness, 0.001 inch too small in the springing out, and 0.01 inch too long in the strip length, then the stress calculation for the above data would be,

$$S = \frac{0.056 \times 13,000,000 \times 0.085}{(2.76)^2}, \text{ or}$$

$$S = 8,210 \text{ lbs./in.}^2$$

Thus, there would be an experimental error of about 200 pounds with the errors of measurement indicated. The calculated stresses are, of course, not absolute stresses, but simply indicated stresses on the basis used.

In the application of the strip method for examining the effect of heat treatment on the release of stress, the procedure preferred by the authors is as follows: The cold-worked tubing to be treated is cut into lengths, and the original stress determined by cutting a strip on one side of the samples. The test pieces are then given the prescribed annealing and the stress determined by cutting a strip in the side opposite the first strip. The variation in stress around the wall of a tube may be tested by cutting strips at intervals. It might be asked if cutting a strip in a tube would not largely release the stress throughout the sample, so that cutting a second strip on the opposite side would not give the stress at the second position. The authors believe as a result of their tests that there is substantially no release of longitudinal stress in other portions of a tube by cutting a strip in one portion.

Table 1 gives the results of some internal-stress determinations in the case of cold-worked leaded brass tubing of the nominal composition 66.33:33.17:0.5 Cu-Zn-Pb, of varying sizes, before and after heating for 2.5 hours at 325° C. It will be noted that there is marked stress reduction with only a slight decrease in hardness. This subject will be treated more fully in a succeeding article. It is sufficient to state here that the strip method is a reliable means of noting longitudinal stress release in drawn tubes by heat treatment.

TABLE 1.—Internal Stress in Cold-Worked Leaded-Brass Tubing Before and After Heating for 2.5 Hours at 325° C.

Outside diameter of tubing.	Thickness of tubing.	Measured springout.			Calculated stress.			Brinell hardness. ¹	
		Before heating.	After heating.	Additional spring.	Before heating.	After heating.	Stress reduction.	Before heating.	After heating.
Inches.	Inch.	Inch.	Inch.	Inch.	Lbs./in. ²	Lbs./in. ²	Lbs./in. ²		
0.567	0.053	0.051	0.011	0.081	4,650	1,003	3,647	145	143
.631	.052	.020	.014	.049	1,790	1,250	540	153	140
.713	.067	.043	.038	.076	4,950	4,375	575	139	133
.878	.069	.065	.016	.100	7,710	1,895	5,815	140	135
1.080	.058	.040	.022	.069	3,990	2,190	1,800	127	125
1.147	.077	.073	.022	.123	9,675	2,915	6,760	136	136
1.223	.062	.105	.044	.165	11,190	4,600	6,590	124	120
1.309	.073	.099	.023	.116	12,420	2,895	9,535	130	122

¹ Le Grix machine; 1/16-inch diameter ball, 25.2 kg, 30 seconds.

V. SUMMARY.

1. Accelerating cracking agents were found to be of no value in detecting the presence of stress in certain lots of leaded brass tubing with cold reduction in area from 17 to 65 per cent.

2. Because a wrought brass does not crack under the application of an accelerating cracking agent, it does not follow that the material is free from internal stress.

3. Machining by Heyn's method failed to show length changes; that is, failed to disclose the presence of stress in the tubing investigated.

4. Cutting diametral rings failed to show evidence of circumferential stress in the same tubing.

5. The stresses in some brass tubes have been shown to be only longitudinal, tensile, and compressive stresses.

6. A method designated by the authors, the strip method, was developed for detecting the presence of longitudinal internal stress, and for measuring quantitatively such stress in drawn brass tubes.

7. The strip method can be applied in determining the laws governing the release of stress in cold-drawn internally stressed tubes on heat treatment.

WASHINGTON, November 12, 1923.