Brazing Copper Tubing Better and Faster

By:

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One of the most common but widely abused joining processes is torch brazing of copper tubing. This article explains basic brazing concepts, including joint design, the behavior of filler metal and metallurgical aspects of making brazed joints. This article will show fabricators and contractors how to make sound joints that are just as strong as the copper tube, easier for the brazer to make and less expensive to produce.

Strength of Tube Joints

Butt joints between copper tubes can be just as strong as the copper itself provided the filler metal is sufficiently strong. This is because all of the load must be carried through the contact area of the two small surfaces at the ends of each piece. See Figure 1. Butt joints are not normally used to join copper tube because maintaining alignment during brazing is too difficult.

Socket joints, on the other hand, are self-aligning during assembly and brazing. In a socket joint, the filler metal does not have to be as strong as the copper since the contact area between the tube and socket can be made large. See Figure 2. When the bonding area is large, the stress through the braze metal is low and the filler metal can be much weaker than the base metal. This allows one to use soft solders (tensile strength around 5,000 psi) to join much stronger copper tube (tensile strength around 30,000 psi) by using fittings that have deep cups.

Design of Socket Joints

A tube joint has to be strong enough to carry loads such as pressure, dead weight, thermal expansion, etc. If we select a combination of filler metal and socket depth such that the joint is stronger than the tube, the tube itself becomes the limiting factor in the design.

The strength of a torch brazed socket joint depends on:

- the length of the overlap (usually the socket depth)
- the strength of the filler metal
- the soundness of the joint.

Using these variables, the required depth of insertion can be approximated using the following formula:

$$X = tW/0.8L$$

Where:

X is the required overlap
t = the tensile strength of the base metal
L = the shear strength of the braze metal or solder
W = the thickness of the thinner member
0.8 is the soundness (or safety) factor

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When a copper-to-copper joint is soldered, the tensile strength of the copper is about 30,000 psi and the shear strength of the solder is about 5,000 psi. For tube that is 0.065 inches thick, the overlap needs to be 0.48 inches, or 8.7 times[1] the thickness of the tube

When a copper-to-copper joint is brazed with any BCuP or BAg type braze metal, the shear strength of the braze metal is about 25,000 psi. For a tube that is 0.065 inches thick, the overlap needs to be 0.100 inches, or 1.5 times the thickness of the tube.

These relationships are plotted on Figure 3. Table 1 shows the results of tension tests for socket joints torch brazed and soldered using various overlaps. Cross-sections of the various joints are shown in Figure 4.

The fact that only a very small overlap is needed for brazed joints is not new information. In the late 1950s, over 1200 tensile test specimens were brazed in a round-robin series of tests performed by 10 labs. These tests were performed on the following with various overlaps:

1) 410 stainless steel furnace brazed using BNi-1
2) Mild steel furnace brazed with copper
3) Copper torch brazed with BAg-1
4) Mild steel torch brazed with BAg-1.

The results of all of these tests showed, as did our results, that very little overlap is needed in a brazed joint to get full strength. The report was published as AWS C3.1-63, and in all cases, base metal tensile strength was reached when the overlap was twice the thickness of the members (2t). It should be noted that small overlaps are commonly used today when branch joints are made using T-Drill™ as shown in Figure 5.

Although the "2t" overlap rule works for many commonly used combinations of materials, it is possible to pick a combination of base metal and filler metal (e.g., stainless steels brazed with pure silver) where greater overlap is required to achieve full strength in the joint. One should always verify the adequacy of the minimum overlap one intends to use by testing.

The Down Side of Overlap

The depth of insertion affects two significant aspects of brazing -- the strength of the joint and the ease with which a joint is brazed. Although it appears from a strength viewpoint that more overlap is better, overlap beyond two times the thickness of the thinner member (2t) does not increase the strength of the joint any further; in fact, increasing the overlap much beyond 2t only makes it more difficult for the brazer to make a sound joint! There are two reasons for this.

First, the braze metal has to flow into a small gap between the parts for the entire length and circumference of the joint. Although there are other factors, one obvious obstacle is that the longer the overlap is, the further the braze metal has to flow and the more opportunity there is to trap gas which causes voids in the joint. An adequate supply of flux and uniform heating of the joint to an adequately high temperature promotes the flow of the braze metal into the joint, but as overlap increases and the diameter becomes larger, proper flow becomes more difficult.

[1] Due to creep of solder at ambient temperature, solder joint fittings are actually designed based on a unit stress of 235 psi, and are limited to maximum pressures at various temperatures in accordance with ASME B16.22. As a result, solder joint fitting socket depths can be 10t or more in depth..

Second, brazing rod begins to melt at a temperature that is lower than the temperature at which braze metal is fully liquid. This temperature is called the *solidus* temperature. Just above this temperature, the braze filler is a mixture of solid plus liquid. It is thick and slushy, much like a frozen Margarita. In this condition, the metal does not flow very easily into a closely-fitted joint. Imagine sipping a frozen Margarita through a small straw quickly. – it is difficult!

As the filler metal is heated more, it becomes more completely liquid until it reaches the *liquidus* temperature. At this temperature, the filler metal is fully liquid and flows readily into the tiny space between the parts. The Margarita is now melted (yuck!) and flows through the small straw easily.

The solidus and liquidus temperatures for common brazing filler metals are found in Table 1; others can be found in AWS/ASME A/SFA 5.8 and in manufacturer's literature.

To complicate matters further during brazing, a small amount of the copper base metal dissolves into the filler metal and a small amount of the alloying elements in the filler metal diffuse into the copper base metal. When this happens, the chemical analysis of the filler metal changes; this increases the liquidus temperature, and the filler metal turns thick and slushy even though it is quite hot. As noted above, thick, slushy filler metal does not flow into the joint easily.

Fortunately, this diffusion/dissolution process is slow compared to the time that it takes for braze metal to flow into a properly heated joint. However, if the joint is not adequately heated before braze metal is introduced, the braze metal starts out slushy and becomes thicker as the brazer reheats the joint. The longer the joint is at brazing temperature, the more the braze metal composition becomes like the copper itself. This explains why it is nearly impossible to get a brazed joint to remelt after it has been used to make a joint.

Diffusion is not all bad, however. Jet engine compressors, for example, are used at temperatures above the melting temperature of the braze metal that holds them together. In this application, the parts are held in a furnace at diffusion temperature so long that the braze metal is totally dissolved in the base metal and the joint is effectively gone. This is a good thing since it allows the engine to stay together in service.

Using Solder-joint Fittings when Brazing

If excessive overlap makes getting a sound brazed joint unnecessarily difficult, why does the industry use fittings solder-joint fittings that have so much overlap? The answer is simple -- lawyers. Ordinary copper and brass fittings are manufactured to be soldered, not brazed. They typically give the craftsman 10t overlap or more, which is what is needed to ensure adequate strength if the joint is made with solder. See Table 2. Since fittings manufacturers have little control where their fittings will be used or how they will be joined, the least risky thing for fittings manufacturers to do (this is where the lawyers come in. . .) is to make all the fittings suitable for soldering. Solder-joint fittings can be brazed, but the cup depth makes life difficult for brazers. Fittings that have short cups that are designed for brazing are available and are much easier to braze than solder joint fittings, but they are typically special order items with very limited distribution. A contractor who supplies such fittings to his craftspersons faces the same liability risks described for fittings manufacturers, so care should be taken if one buys and makes braze joint fittings available to his craftspersons.

Does having excessive overlap really result in poor quality joints to the point where a contractor has to take action? Studies performed by the Air-Conditioning and Refrigeration Institute (www.ari.org) and Copper Development Association (www.cda.org) confirm that it becomes progressively easier to make poor-quality brazed joints as the depth of insertion (overlap length) increases.

Qualification of Procedures and Brazers Using Solder-joint Fittings

When a Brazing Procedure Specification (BPS) is qualified under ASME Section IX, the minimum overlap that will be used in production must be used during qualification. That is, if the overlap used on the test coupon was 1/4 inch, the minimum overlap that must be used in production is 1/4 inch. One should also be sure that the production overlap is at least twice the thickness of the thinner part to be joined (2t) as noted previously. This ensures adequate joint strength for production joints. There is no maximum overlap length required in the BPS.

When a torch brazer is qualified, he is limited to the overlap that was used on his test coupon plus 25%. That is, if the brazer's test coupon overlap was 1/2 inch, the maximum overlap that he is permitted to use during brazing is 5/8 inches. There is *no minimum overlap for the brazer* since a brazer who can properly braze a deep socket can also braze a shallow socket.

Making Life Easier for the Brazer

Since only a small overlap is necessary (2t) to achieve full strength in a brazed joint, the full depth of a solder joint fitting is not needed. More socket depth just adds to the suffering of the brazer when making a joint! To make matters worse, the bigger diameter the tube is, the deeper the socket and the more difficult the joint is to make.

Several things can be done, especially with larger fittings, to make the brazer's life easier:

1) Buy braze-joint fittings. To the best of the writer's knowledge, they are not readily available commercially. Besides, having them on the shelf runs risk of an unaware employee using them with solder which will lead to failure which is followed by lawyers, general malaise, depression, loss of sleep, loss of profits, etc.
2) Have a machine shop trim the excess off as needed for the work. This works but is quite expensive.
3) Have the brazer trim off the excess cup in the field. This is prohibitively expensive and will probably result in distorted fittings, bad fitup and poor quality joints.
4) Fit the pipe into the tube with only a short overlap. Although this works, it is very difficult to control since the tube is free to move in and out of the fitting during assembly.
5) Deform the fitting near the end using a tool such as that shown in Figure 6. This tool limits the depth of insertion and provides a positive tube stop (see Figures 7 and 8) so that proper insertion depth can be maintained easily. The amount of braze metal saved by using such a tool is shown in Table 3. A significant reduction in time needed to make a joint is expected, but the writer has no data at this time.

Conclusions

Several conclusions can be drawn from the above discussion.

1) It is not necessary to insert copper pipe completely into a solder-joint socket to develop full strength in the joint when brazing. A depth of insertion twice the thickness of the thinner member is adequate with BCuP and BAg-type braze metals commonly used on copper. For other metals, testing should be done to determine the adequacy of the overlap that will be used.
2) The deeper the tube is inserted into the socket, the more difficult it is for the brazer to make a sound joint. The larger the tube, the deeper solder-joint fittings are and the more challenging

brazing them is for the brazer. Deeper sockets and longer overlap only make brazing more difficult for the brazer and add nothing to the strength of the joint.

3) Controlling the depth of insertion to 2 to 4 times the thickness of the thinner member will improve the consistency of brazed joint quality.
4) To achieve this overlap control, one can use braze-joint fittings with full insertion, solder joint fittings with partial (but adequate insertion) and to use solder joint fittings that have been mechanically shortened.
5) Limiting the joint depth reduces the brazing filler metal required and the time to properly heat and complete the joint, decreasing cost and increasing productivity.

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Table 1

Tensile strength of torch brazed copper joints at various overlaps

Joint type and overlap	Specimen 1	Failure Location	Specimen 2	Failure Location
Butt Joint	38,390	Base Metal	39,190	Base Metal
Socket, 1t overlap	32,900	Base Metal	34,040	Base Metal
Socket, 2t overlap	34,310	Base Metal	35,640	Base Metal
Socket, 3t overlap	31,590	Base Metal	36,610	Base Metal

Tube was 1-1/2 in size with 0.045 in wall thickness.
Braze metal was AWS/ASME A/SFA 5.8 BCuP-5

Table 2

Common Copper-based Brazing Filler Metal Composition
and Melting Characteristics

Grade	Silver	Phosphorous	Zinc	Copper	Solidus °F	Liquidus °F	Span, ºF
BCuP-3	5%	6%	•	89	1190	1490	300
BCuP-4	6%	7.3%	•	86.7	1190	1325	135
BCuP-5	15%	5%	•	80	1190	1475	285
BCuP-6	2%	7%	•	91	1190	1450	260
BCuP-7	5%	6.7%	•	88.3	1190	1420	230
BAg-7	56%	•	17%	27	1145	1205	60

• indicates not added

Table 3
Depth of Solder Joint and Braze Joint Fittings

Pipe Size	Solder Joint Socket Depth [2]	Brazed Joint Socket Depth [3]	Percent of braze metal saved using 3/8 in. overlap[4]
1/4	0.31	0.17	N/A
3/8	0.38	0.20	N/A
1/2	0.50	0.22	24
3/4	0.62	0.25	37
1	0.75	0.28	48
1-1/4	0.97	0.31	59
1-1/2	1.09	0.34	63
2	1.34	0.40	69
2-1/2	1.47	0.47	71
3	1.66	0.53	73
3-1/2	1.91	0.59	75
4	2.16	0.64	77
5	2.66	0.73	79
6	3.09	0.83	81

[2] Based on ANSI B16.22
[3] Based on MSSSP 73 for Type L copper
[4] compared to solder joint fittings. Includes allowance for full fillets on both ends of the joint

Figure 1

Butt Joint Bonding Area

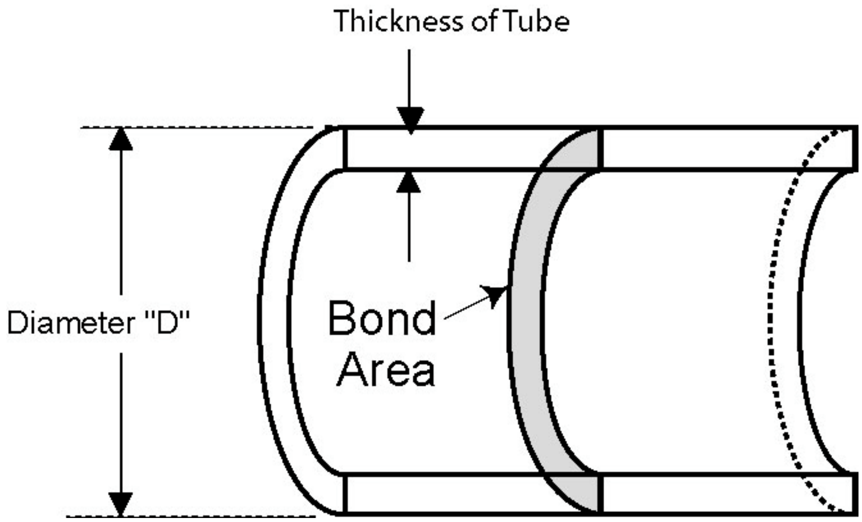

Figure 2

Typical Socket Joint for Soldering or Brazing

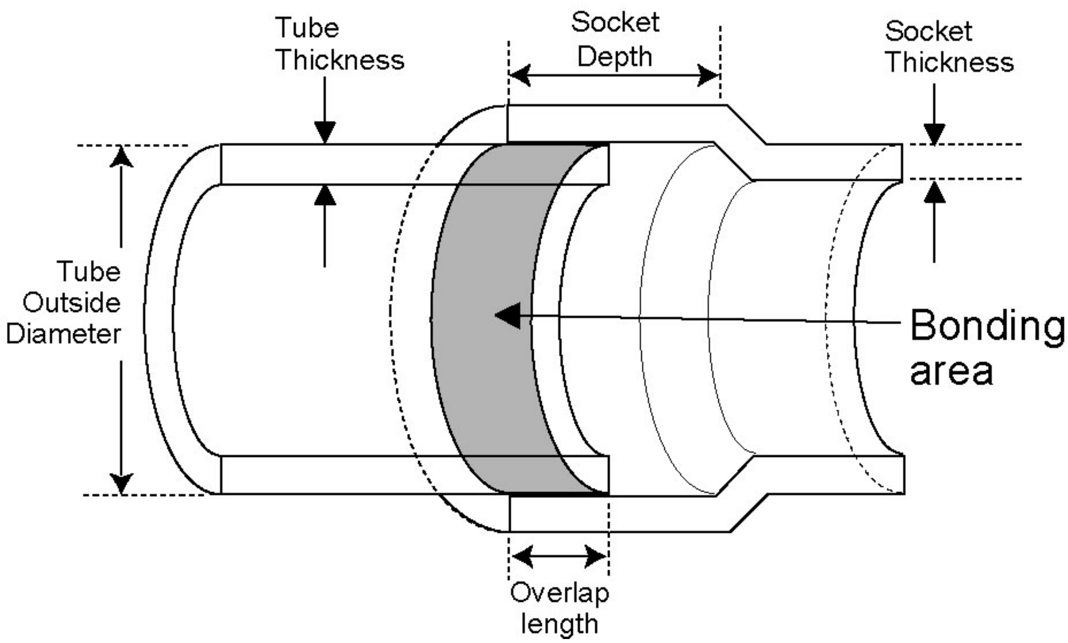

Figure 3

Relationship of Joint Strength and Shear Stress to Overlap Length for Soldered and Brazed Joints

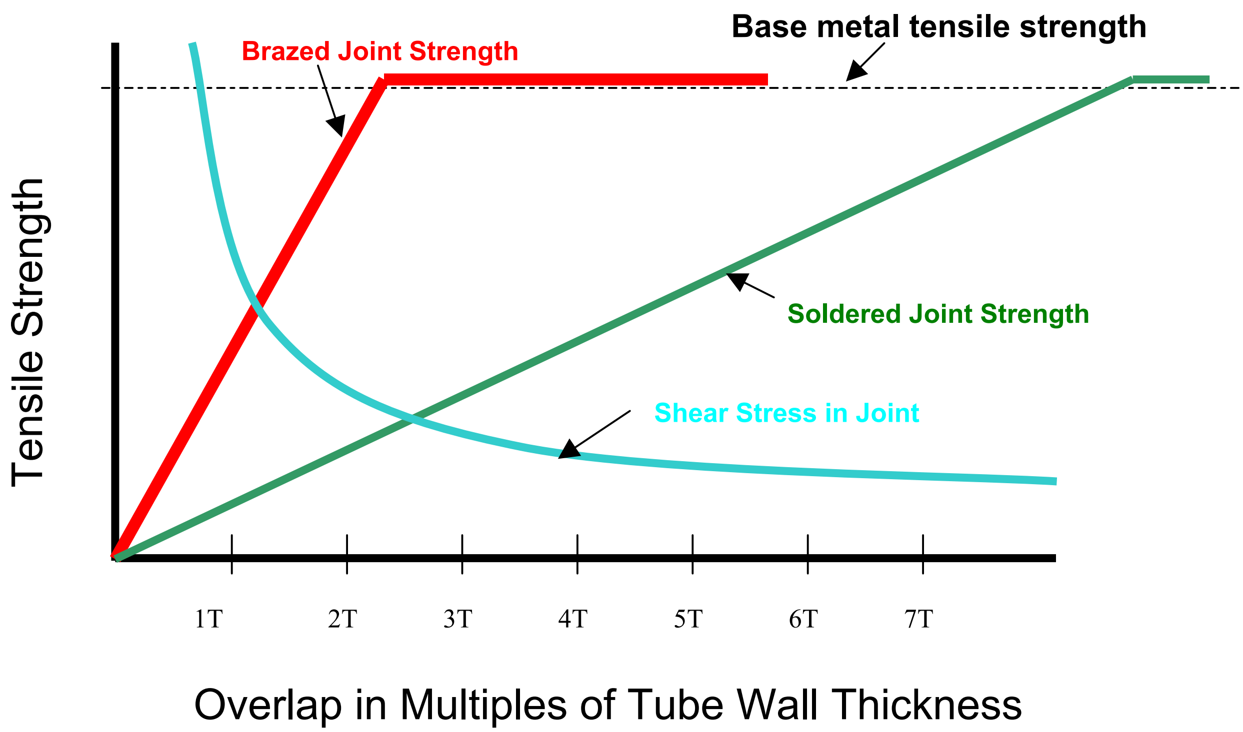

Figure 4

Copper Lap Joints Torch Brazed using BCuP-7 without flux.

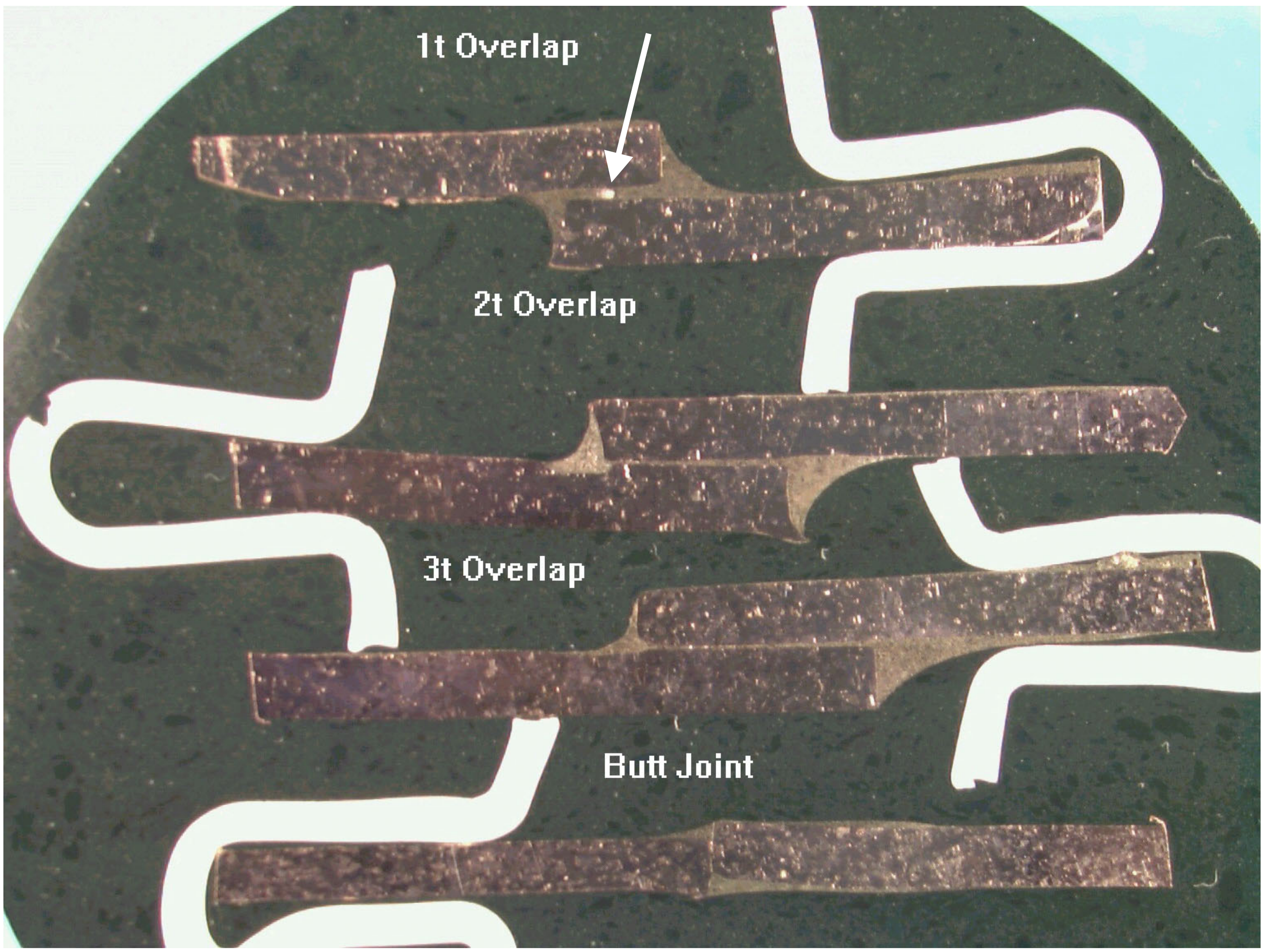

Figure shows a butt brazed joint and lap joints with 1t, 2 t and 3 t overlap. There is porosity at the white arrow.

Figure 5

T-Drill Joint

Figure shows depth of socket in a T-Drill joint. The arrows show the depth of the socket. *T-Drill joints must be brazed, not soldered!*

Figure 6

Solder Joint Fitting Modification Tool

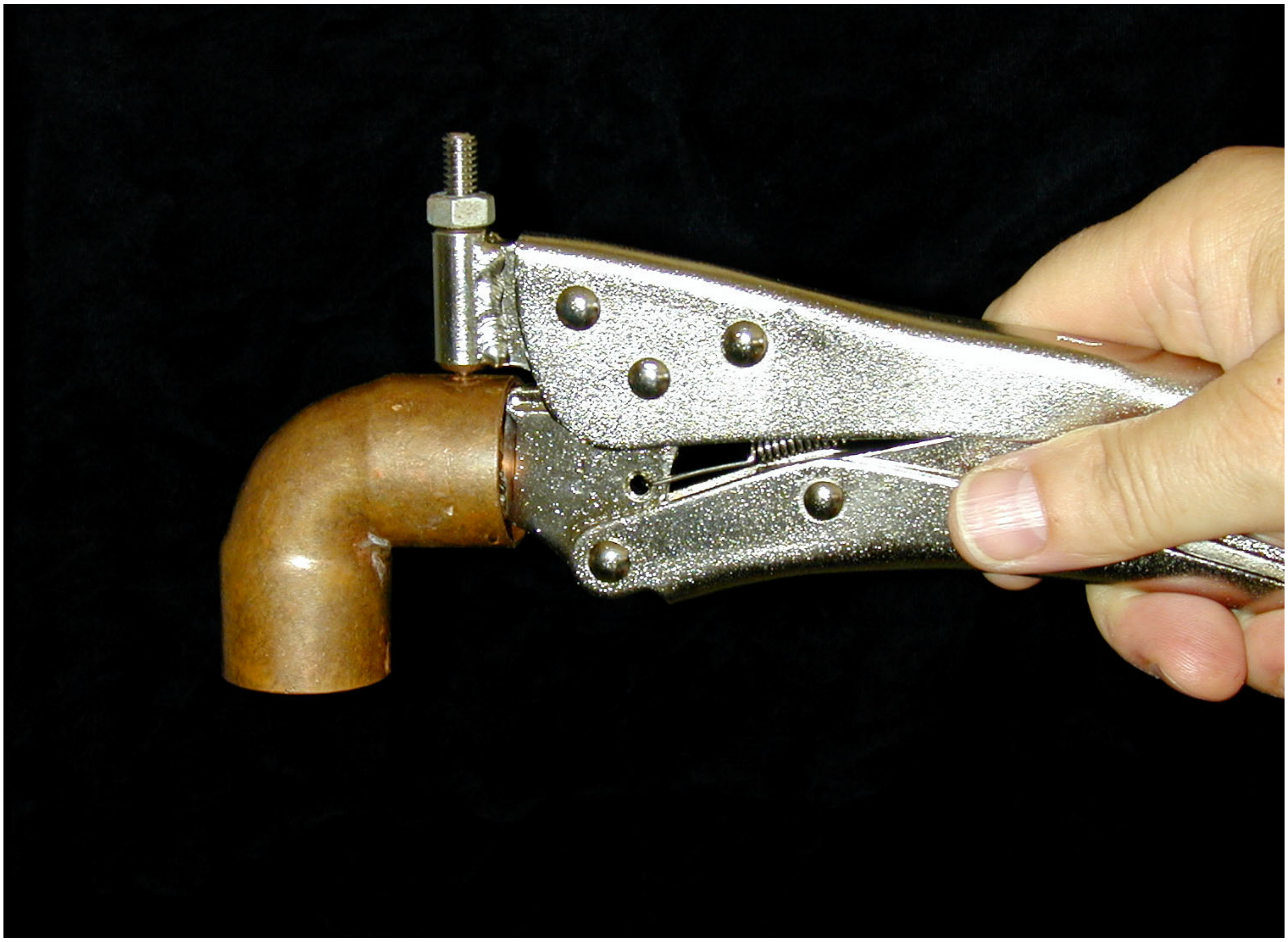

Figure shows a tool designed to hold the fitting firmly between the jaws and make a shallow impression in the fitting wall. Depth of the dimple is preset for the thickness of the fitting to achieve a small protrusion on the inside of the fitting This tool is patented by Brazing Dimpler Corporation and is available at www.brazingdimpler.com.

It should only be used for joints that will be brazed, not soldered. The full depth of the socket must be used if the joint will be solered.

Figure 7

Solder Joint Fitting After Modification by Tool Shown In Figure 6

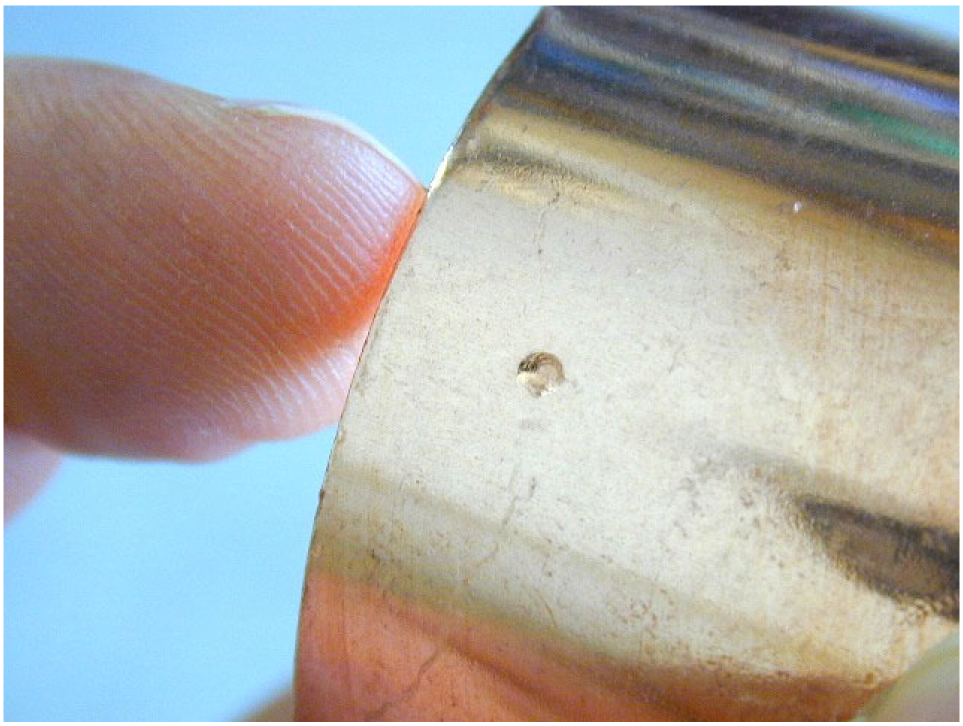

Figure shows an impression left in the fitting wall using the tool shown in Figure 6. The impression protrudes inside the fitting about 0.010 inches which is sufficient to limit the depth of tube insertion. See Figure 8. Three impressions uniformly spaced around the fitting will maintain alignment between the fitting and the tube.

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Figure 8

Solder Joint Fitting After Modification by Tool Shown In Figure 6