Making Stress-Free Solder Joints for High-Stress Performance

BY ANDREW G. KIRETA JR.

Copper piping systems for myriad applications have been joined using strong, reliable soldered joints since copper tube and fittings were introduced to the United States some 75 years ago. Since that time, nothing has changed with what makes a strong soldered joint — the joint still needs to be filled with enough solder to resist the stresses of the system. But, our understanding of what makes this happen, and the materials used to make this happen have seen some changes in recent years.

Solder Joint Ratings – soaring to new heights

One of the biggest changes occurred in 1986, when the use of 50/50 tin-lead solder was banned for use in potable water systems. Almost in an instant, plumbers had to put down their trusty rolls of 50/50 solder in favor of 95/5 tin-antimony solder, virtually the only lead-free solder available at the time.

I'm sure many of you reading this can attest to the fact that this was truly a bad day and, for some, perhaps a bad week, month or year. The forgiveness found in 50/50 solder was gone. The new 95/5 solder tested your abilities and your patience, as the frequency of solder joint leaks as you never had before had you scrambling back to your truck searching for a roll of 50/50 that just might have been rolling around under the seat.

Thankfully, those days are long behind us, and solder manufacturers have created a variety of new lead-free solder alloys to regain the forgiveness and joining ease found with the long-gone 50/50. But how do these solders compare with the 50/50 solder in

strength and longevity?

Table 1 shows the results of solder joint testing performed by Copper Development Association Inc. (CDA) and the National Institute of Standards and Technology (NIST). These results show the long-term strength of 95/5 solder as well as two selected lead-free solders, all of which were much stronger and far outlasted 50/50 solder. These new solder joint pressure ratings have been developed to allow you to take advantage of this increased strength in the design of your systems.

With room temperature pressure ratings exceeding 325 psi, not only are soldered joints using 95/5 and the new lead-free alloys stronger than the old 50/50, they also produce joints that are stronger, more resilient and more reliable than those used in alternative materials systems, such as solvent-cement or crimped insert joints. This strength can be important in withstanding the repeated temperature and pressure variations due to normal plumbing system operation or even water hammer.

Table 1, excerpted from the CDA Copper Tube Handbook.

Joining Material[3]	Service Temp, ºF	Maximum Working Gage Pressure (psi), for Standard Water Tube Sizes[1,2]				
		Nominal of Standard Size, inches				
		1/8 through 1	1 1/4 through 2	2 1/2 through 4	5 through 8	10 through 12
Alloy Sn50 50-50 tin-lead solder[4]	100	200	175	150	135	100
	150	150	125	100	90	70
	200	100	90	75	70	50
	250	85	75	50	45	40
Alloy Sb5 95-5 tin-antimony solder	100	1090	850	705	660	500
	150	625	485	405	375	285
	200	505	385	325	305	230
	250	270	210	175	165	125
Alloy E	100	710	555	460	430	325
	150	475	370	305	285	215
	200	375	290	240	225	170
	250	320	250	205	195	145
Alloy HB	100	1035	805	670	625	475
	150	710	555	460	430	325
	200	440	345	285	265	200
	250	430	335	275	260	195

Soldering Fluxes – Time for a Change

A more recent advance has also come in the form of a materials change. In 1992, to address an increasing number of corrosion problems due to the improper use of soldering fluxes, the American Society for Testing and Materials (ASTM) produced the ASTM B 813 Standard Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube.

Currently, all of the model plumbing and mechanical codes throughout the United States require the use of ASTM B 813 fluxes as the only fluxes allowed for use with copper systems. More and more state and local codes are also adopting this requirement.

Much like the experience with 50/50 solder, the plumbing industry as a whole has looked on these new fluxes with trepidation. One of the most common complaints heard about the new B 813 fluxes was that they were prone to burning. Once again, your soldering abilities and patience were tested as the forgiveness in the flux was reduced, and you experienced more joint leaks during testing.

As before, manufacturers rose to the challenge to improve the new fluxes to be more forgiving and usable. Today, it would be difficult to differentiate between joints made with B 813 fluxes compared to those made with the fluxes of old.

To prove this, CDA performed a blind test using five different mechanics of varying soldering ability and experience. The mechanics were asked to make soldered joints on 2”x2”x1” copper tees using the three different solder alloys shown in Table 1, and nine different fluxes (six meeting ASTM B 813 and three old-style fluxes) The mechanics had no way of knowing which flux and solder combination they were using on any given joint.

Overall, 800-plus joints were made, sectioned and peeled for examination of the joint surfaces. The results were surprising. Regardless of which mechanic made the joints and which solder alloy was used, three of the six B 813 fluxes used clearly resulted in better joints (less trapped flux pockets, better solder coverage and fill) than the three old-style fluxes used. The joints made using the remaining three were virtually indistinguishable from the old-style fluxes.

The transition to B 813 fluxes in the marketplace has been much slower than the transition from 50/50 solder. While this has been helpful in allowing the B 813 fluxes to evolve into better, more user-friendly products, it has allowed the use of fluxes that do not meet industry standards or recommendations to linger. Remember, every job that you install using a flux that doesn’t meet the ASTM B 813 standard is one that may not meet the code and may result in a costly call-back in the future.

Soldering Techniques — Teaching Old Dogs New Tricks

Probably the most important factor in making strong, reliable solder joints is the person behind the torch. The plumber or mechanic is solely responsible for putting all of the materials to work — the copper tube and fittings, the flux, the heat of the torch, and the melting of the alloy — to make joints that hold for the life of the system.

Soldering has always been a very forgiving process, even marginal solder joints can give a lifetime of service. However, with the changes to solders and fluxes already discussed, it is more important for installers to learn and adhere to the industry recommended process for making quality solder joints.

This practice is outlined in detail and standardized in the ASTM B 828 Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings. For a detailed review of this process you can reference the article “Soldered and Brazed Joints” (Reeves, May 2003) or the CDA Copper Tube Handbook available at www.copper.org.

The soldering process is generally

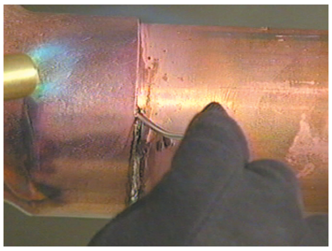

Figure 1: Proper application of heat to the soldered joint: heat is at the base of the fitting cup slightly ahead of the solder metal as both are moved in unison up the side of this joint

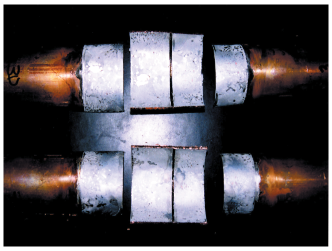

Figure 2: A quality soldered joint: full solder penetration and fill, as exhibited by the dull gray appearance of the solder metal on the majority of tube and fitting surfaces

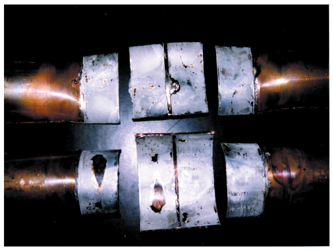

Figure 3: Trapped flux pockets: the black and brown appearance indicates that the flux was burned

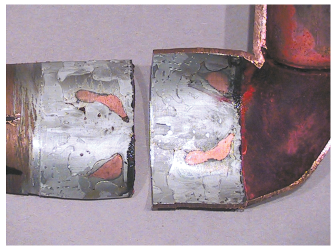

Figure 4: Trapped flux pockets: shiny, wet surfaces indicate the flux was trapped, not burned, an indication of improper technique

outlined in a series of nine steps: measuring, cutting, reaming, cleaning, applying flux, assembly and support, heating, applying filler metal, and cooling and cleaning. It is not the intent to cover these in detail here; for more information, see the references above. Instead, it would be useful to discuss some things you can look for to help diagnose which parts of your technique may be causing problems.

For the most part, the nine steps listed above are straightforward and depend little on individual technique. Reaming, for example — as long as you ream the tube ends to remove the burr left from cutting, you've accomplished the goal; it doesn't really matter how or with which tool. On the other hand, the steps of heating and applying filler metal depend a great deal on the technique used. It is in these steps where we find the most opportunities for producing less-than-ideal solder joints.

ASTM B 828 outlines in great detail the proper application of heat and filler metal to make a sound solder joint. In a nutshell, the heat (torch) must first be applied to the tube to bring it up to soldering temperature. The heat is then transferred to the base of the fitting cup to bring the fitting to soldering temperature. Then, with the heat remaining at the base of the fitting cup to keep the tube and fitting at temperature and promote capillary action, the solder metal is applied to the face of the joint.

In horizontal joints, it is of utmost importance to start the joint with the heat and the filler metal both at the bottom of the joint, and then proceed to move both up the side of the joint, keeping the heat slightly ahead of the solder metal. In vertical joints, either up or down, the starting point is not critical, but the relationship of the application of the heat (at the base of the fitting cup slightly ahead of the point where the solder is being applied) and the application of the solder is generally the determining factor between good and poor solder joints.

This relationship, between the torch and the filler metal, is of primary importance in making a quality solder joint. The proper relationship between the two, with the point of application of the heat slightly leading the point of application of the solder metal (Figure 1) will ensure the molten solder will push the soldering flux out of the joint and fill the joint with solder. An improper relationship between the two, either trailing the application of the solder with the heat, or keeping the heat in one place while applying the solder will lead to trapped flux pockets in the joint space and a lack of solder fill, and lead to poor joints.

So how can you tell where your technique can use improvement? The only way is by making and destructively testing your own solder joints.

Are you up to the Test?

To improve your soldering technique and evaluate how your solder joints stack up, all you have to do is make some joints and then peel them to examine the joint surfaces. This is easier than it sounds. For a true test, you should use joints that are at least 1-1/4" in size so that differences start to stand out. As you make the solder joints, mark the top and bottom of horizontal joints, your starting position on vertical joints, etc., to give you a point of reference. When the joints are cool, use a saw to cut the joints in half longitudinally along the axis of the tube/fitting. Then, flatten the joints using a hammer or bench vise and peel the tube from the fitting to examine the joint surfaces.

In a perfectly made solder joint, both the tube and fitting surfaces should be covered with dull gray solder metal, indicating that the solder metal "tinned" both surfaces and filled the capillary space, "bridging" the two surfaces. The dull gray appearance of the solder metal (Figure 2) indicates that the solder was physically separated when the joint was peeled. Be prepared, we see few truly perfect joints.

In reality, you are likely to see minor imperfections in your solder joints. These can include areas where flux was trapped in the joint and solder could not enter, neither "tinning" nor "bridging" these areas. You may also find areas where solder entered the joint and tinned the tube and fitting surface but did not bridge the capillary space. It is the appearance and location of these defects that will guide you to improvements in your soldering technique.

Areas of shiny, silver solder metal on both the matching tube and fitting surfaces indicate areas where the solder tinned the tube and fitting, but did not bridge the capillary space between the two. This is not a factor of the flux, because at the point that tinning of the surfaces occurred, the flux had done its job. Instead, it is usually the result from one of two conditions — solder starvation or overheating.

Solder starvation is just what it sounds like, not enough solder metal was added to the joint to fill the joint space. How much is enough? There is no magic answer to this. It's not one times the joint diameter, or two times the joint diameter. The answer is that the joint will tell you when you've added enough solder. If you are adding solder at one point, say at the bottom of a horizontal joint, once the capillary space is filled there is no where for the solder metal to go — it will run out of the front of the joint and drip on the floor. It is at that point that you've added enough solder at that spot and should move on around the joint. While no one wants to waste solder metal, practice will allow you to see when the joint fills at the point of application and you can move without sending half your roll of solder to the floor. Although half a roll of solder on the floor is probably less expensive than repairing one leak in the system.

Overheating of the joint can also result in areas where a lack of bridging occurs. This usually happens when you have completed your solder joint and decide to go around the joint again (or again and again) to try to dress it up. Remember, solder melts and flows when it is heated. If you follow the proper steps to heat and fill the joint with solder, the more time that you spend heating the joint after it is made will only melt the solder out of the joint and make for a weaker joint.

Areas of trapped soldering flux in the joint spaces are much easier to spot, and much more indicative of technique flaws. The location and condition of these flux pockets — areas where neither the tube nor fitting surfaces are tinned — can indicate where these flaws exist. For example, flux pockets that exhibit black or brown charred surfaces (Figure 3) indicate that the flux was burned as the joint was being made. Either too much heat or too much time was taken to make the joint, or both.

The solution is usually as simple as evaluating which size torch you are using in relation to the size of the joint being made, manufacturers make different sizes for a reason and offer good sizing recommendations. Also, burning the flux can result from trying to heat the entire joint assembly through the fitting. In doing so, you are trying to heat the tube surface through the fitting, the flux, and the capillary space and can burn the flux before the tube comes to soldering temperature. Proper heating technique, preheating the tube then the fitting, will overcome this problem.

Flux pockets that are trapped but not burned — exhibiting wet, shiny copper surfaces (Figure 4) — generally indicate failure to maintain the proper relationship between the point of application of the heat and the application of the filler metal. Maintaining the point of application of heat at the base of the fitting cup, slightly ahead of the solder metal is essential in preventing trapped flux pockets.

Applying the heat behind the point of application of the solder, or keeping the heat in one place as the solder is applied around the joint allows the solder to create a cap at the face of the solder joint, through which the flux cannot escape the joint and becomes trapped. Remember, a trapped flux pocket will always prevent solder from filling that space.

The position of these flux pockets also offers clues to help improve your technique. A flux pocket trapped at the top of a horizontal joint, normally in the shape of a V or U with the open end to the base of the fitting cup, usually indicates a joint that was made by applying the heat at the bottom of the joint and applying the solder at the top — a sure way to never get solder metal into the top of the joint.

Flux pockets, or a lack of solder running the entire way around the base of the fitting, generally indicate a failure to apply the heat to the base of the fitting cup. Solder metal flows to the heat, if you don't get the heat to the base of the fitting, you won't pull the solder metal fully into the joint.

Flux pockets trapped in the sides of horizontal joints, or in the middle of vertical joints, generally indicate the failure to continually lead the solder metal with the heat. Remember, where the heat goes, the solder follows.

Quality Soldered Joints

Spending some time analyzing and improving your soldering technique can only serve to make you a better, more valuable installer. Don't be discouraged, perfect solder joints, while nice, are not necessary. Generally, a solder joint that has 70%–80% solder fill, with no voids extending more than 20%–30% of the length from front to back of the joint, should handle all system stresses and provide a lifetime of service. And, as you will see, small changes in your technique can lessen your stress and lead to large improvements in your results.

For more information on the design, specification and installation of quality copper plumbing systems or to receive a free copy of the Copper Tube Handbook, contact Copper Development Association Inc., 260 Madison Avenue, New York, NY 10016, phone: (212) 251-7200. Or visit the Web at www.copper.org where downloadable copies of the handbook and other piping applications are available.

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