Liquation in brazing is defined as the tendency of the lower-melting constituents of a brazing filler metal (BFM) to separate out and flow away (by capillary action) from the higher-melting constituents of the BFM during heating. Sometimes a nonmelted “skull” of alloy remains at the point where the BFM was applied. Liquation is usually apparent in BFMs having a wide melting range, i.e., having a large difference between the solidus and liquidus temperatures. It occurs when the BFM is heated slowly through that melting range (such as when furnace brazing). Liquation is not typically encountered when rapid brazing techniques — flame brazing or induction brazing — are used.

Liquation of a BFM is easily recognized on the outside of a brazed joint because of the separated “lumps” of apparently nonmelted BFM observed along the line of the braze-fillet at the edge of a brazed joint. Examples are shown in Figs. 1 and 2.

**Melting and Solidification of Brazing Filler Metal**

First of all, it’s important to understand how the melting and solidification of an alloy affects liquation. Shown in Fig. 3 are three screen samples that have been furnace brazed. Each screen was placed on a flat steel plate. A quantity of silver-based BFM was placed on top of the screen at its center, and then each was brazed. The photos show the condition of each screen after brazing. Note that in Fig. 3A all the BAg-1 BFM has flowed by capillary action throughout the screen material. In Fig. 3B and C there is a significant amount of nonmelted BFM residue present in the center of each screen, even though much of the BAg-2 BFM has flowed out by capillary action. Now, under laboratory conditions, it can easily be shown that the BAg-1 BFM has a narrow melting range of only about 20°F/11°C (solidus temp: 1125°F/607°C; liquidus temp: 1145°F/618°C) and is known as a “eutectic-type” alloy. Thus, when heated (either rapidly or slowly) during furnace brazing, the eutectic-type BFM will flow out completely, leaving virtually no nonmelted residue behind.

The BAg-2 BFM, by comparison, has a wide melting range of 170°F/95°C (solidus: 1125°F/607°C; liquidus: 1295°F/702°C). Notice in Fig. 3B and C that there is a “skull” of BFM left in the center of the two screens brazed with the BAg-2. Seeing this residue on a brazement might raise the question that since two screens were brazed at a temperature higher than the liquidus temperature of BAg-2, why is there a residue of BFM left at the center of the screen? Something must either be wrong with the BFM or the furnace never got up to brazing temperature. Both these conclusions are incorrect in this situation.

Let’s look more closely at what happens during BFM melting in order to understand how and why liquation can become a problem to a production brazer. Let’s start in the BFM manufacturer’s laboratory to see how it determines the solidus and liquidus temperatures of a BFM and then move to a brazing shop furnace using that BFM in production.

**Determining Liquidus and Solidus**

In determining the solidus/liquidus temperatures for a particular BFM in their laboratory, the manufacturer carefully blends a certain ratio of metallic constituents for that BFM in a laboratory crucible. It is then heated up while carefully monitoring the temperature of the mixture (using special thermocouples) until it starts to melt. When any metal starts to melt, a large amount of energy is absorbed to change it from solid to liquid, and this change is noticed in the temperature chart being recorded. Figure 4 shows some typical thermal-arrest curves for two different types of BFMs. This method of determining melting characteristics of metals is just one of a few that can be used for determining solidus/liquidus temperatures.

Each chart in Fig. 4 shows the rising temperature of the solid metal as it is heated. A break in each curve (change in its slope) will occur when the heat input is no longer being used merely to raise the temperature, but is now being absorbed by the metal as it changes from solid to liquid (Point S on each chart). After all the metal has changed to liquid (at point L) on each chart, all the added heat is once again used to raise the temperature.
perature of the liquid, and the slope of the curve changes again. In Fig. 4A, there is no temperature difference between points S and L, and this would represent the thermal-arrest curve for a eutectic BFM (it all melts at the same temperature). Figure 4B shows the curve for a typical wide-melt-range BFM because there is a large difference between the temperatures of S and L.

Please note that in the laboratory crucible being discussed, all the metal constituents are held inside the crucible and cannot escape. Thus, as melting continues, more and more liquid is formed and surrounds (bathes) any remaining solid materials, helping to dissolve them as they continue to be heated.

Once these thermal-arrest curves have been verified, they will be published by the BFM manufacturer as the true solidus and liquidus temperatures. Please understand, however, that these temperatures are strictly based on laboratory conditions using crucibles to keep all the BFM constituents together while they are being heated and melted.

Any brazing shop using a specific BFM will probably assume that when it is heated in a furnace to a temperature higher than its published liquidus temperature, the BFM will completely melt and flow out by capillary action into the braze joint. This is, unfortunately, often not the case. Instead, when components are examined after brazing, there are sometimes a significant number of lumps of nonmelted BFM along the edge of the joint area (like those in Figs. 1 and 2). What has happened?

Real-World Brazing

The first thing to note is, unlike in the laboratory, the BFM in the brazing furnace is not sitting in a crucible. It has no constraints to keep all the liquid in one place as it melts. Therefore, the first liquid to form will flow away into the braze joint or start to climb out over the hot external surfaces of the part being brazed. Then, when the BFM becomes hot enough for the higher-melting constituents (HMCs) to melt, they may not do so at all since part of its ability to be completely melted (as in the lab) depended on these HMCs being immersed in, and dissolved by, the liquid BFM bath surrounding it. When left alone by itself in the brazing furnace heat with no “surrounding bath” of liquid BFM to help it dissolve, the HMCs may require temperatures far in excess of the published liquidus for that BFM in order for it to actually melt.

Thus, when there is a large temperature difference between the published solidus and liquidus temperatures for a BFM, it is not uncommon in furnace brazing for liquidation to occur and be clearly in evidence along the edge of the resultant brazed joint if the BFM was applied at the outside edge of the joint.

The important thing to remember when this occurs is that the problem does not lie with “bad BFM from the manufacturer” or with “the furnace failed to reach brazing temperature.” Instead, it lies with the inherent melting characteristics of that particular brazing alloy (from any supplier) when it is heated in a brazing furnace.

Here is a quick review of some of the causes of liquidation:

- Using a wide melting-range BFM.
- Slowly heating the BFM through the melt range.
- BFM placed outside the joint to be brazed.

Below are some ways to minimize liquidation.

- Change BFM selection to one that is more eutectic-like (Fig. 3A).
- Heat more rapidly through the BFM melt range (Fig. 3C).
- Bury the BFM inside the joint.
- Shield any externally placed BFM so that it won’t start to melt until the base metal has come up to brazing temperature.

How Bad Is a Brazed Joint that Exhibits Liquidation?

One of the assumptions some people make about liquidation is that since there are lumps of nonmelted BFM around the edge of a brazed joint, the BFM that...
flowed into the joint must not be good. They assume the joint may be weak and prone to early failure if placed in service since everything about the chemistry of the BFM inside the brazed joint itself is unknown. In reality, that’s not the case. The joint may be very high in quality and the liquation merely an aesthetic issue.

**Phase Diagram 101**

Consider the phase diagram (constitution diagram) for the silver-copper alloy system — Fig. 5.

Since there are only two metals involved in this chart, it is called a binary phase diagram. Notice that the line across the center of the chart is labeled “solidus” and occurs at a certain temperature (as shown along the left-hand vertical axis). Within the regions between the solidus and liquidus lines on the chart there is a so-called “mixture” of both solids and liquids present when the BFM is heated above its melting point (i.e., above its solidus). I call these regions “slush zones” since it describes the nature of what’s going on in those regions. It is this slush zone that gives rise to the liquation phenomenon.

Let’s look at what happens when a wide-melt-range composition in the Ag-Cu system is cooled, as represented by the vertical line in Fig. 5. At point A on the vertical line representing the 30% Ag, 70% Cu alloy composition, the alloy is completely liquid. As it is cooled and the temperature crosses the liquidus line, this alloy composition will begin to solidify. The highest melting constituent of that alloy will be the first to start to solidify, and as cooling continues down the vertical line, more and more of the alloy will solidify.

**Lever Law for Phase Diagrams**

Metallurgically speaking, we can now introduce a useful concept known as the lever law. Using this, at any given point vertically along the line (or any similar vertical line at any chemistry), we can determine the actual chemistry of the constituents that are solidifying and coming out of solution as well as the chemistry of the liquid that remains in the joint. The lever law can also be used to determine percentages of phases.

As cooling continues down along the line to point B, the actual chemistry of the phases that are coming out of solution and solidifying will be as shown at point B2 at the far right side of the horizontal line (lever-arm) drawn through point B (a vertical dotted line from point B2 intersecting the bottom axis, tells us what that chemistry is). At the left end of the horizontal lever-arm through point B, i.e., where it intersects the slope of the liquidus line (at point B1), is shown the chemistry of the liquid portion of point B that remains as a liquid in the capillary space in the joint being brazed. The same is true for points C and D as well.

Notice that as the cooling continues down the vertical line, the chemistry of the liquid remaining in the joint is continually changing and follows the slope of the liquidus line. Thus, the last chemistry to exist as a liquid in the joint just prior to complete solidification is the eutectic chemistry, and it is the last component to freeze upon cooling the BFM from brazing temperature.

Now let’s reverse our thinking and start from a solid BFM in a brazed joint to see what happens as we heat that alloy up to the brazing temperature. We will use the

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**Fig. 3 — Samples of furnace brazed screen. A — No liquation of the eutectic-like BAg-1 brazing filler metal is seen; B — example of brazing filler metal liquation of BAg-2; C — same as B except heated more rapidly through the melt range.**

**Fig. 4 — Typical temperature charts for two different brazing filler metals. A — Thermal-arrest curve for eutectic material; B — thermal arrest curve for wide-melt-range brazing filler metal.**

**Fig. 5 — Binary phase diagram for silver-copper (Ag-Cu) alloy system.**

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The Basics

- The solidus temperature is the temperature at which a solid material will begin to melt when it is being heated. We often call it the melting point for that material. The liquidus temperature is the temperature at which a liquid metal will start to solidify when it is being cooled down from the molten state. Thus, it is the lowest temperature at which that BFM will be completely liquid. In brazing, the assumption is often made (incorrectly) that the liquidus temperature is reached when the BFM, upon heating, has finally become completely liquid. Such an assumption for “liquidus” can lead many people into erroneous conclusions about the flowing characteristics of BFMs.
- A eutectic BFM is an alloy of two or more metals that, when heated to its melting point (solidus temperature), will completely melt and turn to liquid at that same temperature (called the eutectic temperature or eutectic point). Thus, there is no melt range associated with eutectic alloys, and its solidus and liquidus temperatures are the same (it is isothermal).
- When the difference between the solidus and liquidus temperatures of a BFM is only 25°F/12°C or smaller, that BFM is known as a eutectic-type BFM since it will behave in much the way as a eutectic BFM.
- Liquid BFM likes to flow toward the heat, i.e., the “hot spots” in any brazing environment. Thus, it will often find the outside surfaces of components much more attractive than the cooler spaces inside the gap waiting to be brazed where the temperatures are somewhat lower than the outside surfaces of the parts.

same chart (Fig. 5) and the same lever-law principles but in reverse. Again, let’s use a BFM composition represented by the same vertical line and see what happens as we heat it up to brazing temperature.

As soon as the BFM temperature exceeds the solidus temperature, it will start to melt, and the chemistry of the first liquid to form should then be — according to the lever law — the eutectic chemistry. This first liquid formed (the low-melting constituent mentioned in the definition of liquidation) will flow out from the BFM by capillary action (either into the joint if the joint is up to proper temperature or over the outside surfaces of the components being brazed, whichever is hotter). The rest of the melting process for the BFM can be studied along the lines (in reverse) of what has been described in the previous paragraphs.

But the key point here is that the first liquid to flow into the joint being brazed is the eutectic composition. From Fig. 3A, we see that the flow of eutectic, or eutectic-like, BFM compositions is smooth and uniform. People who use eutectic BFMs generally find them to be highly desirable for most brazing applications, producing joints of high quality in which the BFM penetrates easily the entire joint, flows freely and is usually highly compatible with the base metals being joined.

Look again at Figs. 1 and 2. The liquidation is readily apparent, but we know the joints can be trusted. It’s now understood that the eutectic composition of the BFM system being used is what flowed into the joint first, and the assembly is probably fully acceptable based on the required strength or hermeticity (leak-tightness). The overall joint may not look very pretty if some liquidation is present, but the assembly should perform fully up to any specification requirements if there is visual evidence that all the joints look fully brazed with no open voids.

When to Reject Brazed Assemblies Exhibiting Liquidation

It is not uncommon for some people to scrap assemblies that exhibit liquidation for the simple fact that liquidation is present since such assemblies in their opinion can’t be any good. Such rejections can be very wasteful and could needlessly scrap parts that might perform perfectly well in service.

The question that should really be asked is: “What will any liquidation residues do to the parts in service from a performance point of view?” If there will be no negative impact on the performance (such as strength, leak-tightness, etc.), then such parts should be put into service.

Liquidation would need to be reworked to remove the surface lumpiness (by grinding, etc.) prior to being placed in service if
- Smooth flow of air across a brazed surface is affected (such as in airfoils).
- Turbulence is created in the flow of liquids across surfaces or through channels where such flow is supposed to be smooth.
- Germs are entrapped or fluids contaminated in the medical or food industries.

Aesthetics of brazed components is another important aspect of liquidation, such as in the jewelry business, where brazing is a common joining method. No person would be happy to receive a brazed piece of jewelry exhibiting poor brazing with lots of liquidation on it. This is a time when perfect brazing is required by the end user, and liquidation is not to be tolerated.

Conclusion

Remember, the acceptability or unacceptability of liquidation should always be based on its impact on end-use service conditions, such as airflow, fluid flows, medical concerns, or aesthetics required by end user. It should never be based on the following false assumptions:
- Liquidation will cause the parts to be weak — False.
- Liquidation will cause the parts to leak — False.
- Liquidation means the parts were brazed incorrectly — False.
- Liquidation indicates that the BFM is of poor quality — False.

This article has explained what liquidation is, what causes it, and how to minimize or eliminate it. Use this new understanding of liquidation in your brazing environment. 