Q: Currently, we are vacuum brazing a round Haynes® 282® alloy cylinder into a 304 stainless steel housing using American Welding Society BNI-2 brazing paste, which we put into a machined chamfer at the top of the joint between the two metal parts. We also apply a special stop-off paste onto the top of the chamfer on the Haynes 282 side of the joint to keep the filler metal from flowing onto the external surfaces of the alloy. We then braze at 1040°C for 1 h. Although the assembly seems to braze okay, and passes our in-house pressure tests, we’re dismayed to see that the stop-off we applied didn’t prevent the filler metal from getting onto the Haynes 282’s external surfaces — Figs. 1 and 2. It appears the filler material “jumps” across the stop-off material placed on the inner edge of the joint, and then proceeds to flow right onto the Haynes 282 cylinder. Parts are oriented so gravity should help the filler metal flow down into the joint, not go over the stop-off and up onto the surface of the Haynes alloy. Do you have any ideas as to why the stop-off is not working?

A: You present a most unusual situation that is not normally seen with stop-off materials, and thus requires careful analysis of the entire brazing setup — including braze prep, amount and positioning of the brazing filler metals (BFMs) and stop-off, heating procedures used, as well as the brazing furnace and brazing cycle — to get clues about what may have happened.

First of all, it is important to understand that brazing stop-off materials are complex blends of metal-oxide materials and a carrier (such as a gel binder or liquid solvent), which is placed onto, or next to, the surfaces that you wish to protect. Two of the most common oxide powders used in making brazing stop-offs are aluminum oxide and titanium oxide.

It is also important to understand that BFMs do not like to bond to, or flow over, oxides (whether such oxides are present as a stop-off compound, or just surface oxidation on the metal surfaces that are to be brazed). Thus, molten BFMs will usually stop spreading over metal surfaces when they encounter brazing stop-off materials, unless other physical, outside forces intervene.

You indicated that one of the base metals being brazed is Haynes® 282®, This metal is a nickel-chromium-moly alloy that contains more than 2% titanium (Ti) and about 1.5% aluminum (Al). Both the Ti and the Al in that alloy will readily oxidize as you heat the parts up to brazing temperature, and those oxides don’t dissociate much at brazing temp. The chromium in that alloy will also oxidize on the way up to brazing temp, but chromium oxides can be readily dissociated at the brazing temperatures you indicate and will not be as much a problem as Ti and Al in the metal.

Plating is recommended. Because any base metal containing more than about 0.5% Ti and/or Al can oxidize sufficiently during heating to negatively affect the wettability/brazeability of those surfaces, I always recommend that people nickel plate (electrolytic nickel plate) any such surfaces prior to brazing.

Notice that in Figs. 1 and 2 the Haynes 282 is dark in color (due to the formation of Ti and Al oxides during heating), and notice, too, that the molten BFM that got onto those surfaces does not spread much, but tends to be localized, and held in a round bead-like shape showing only a little bonding interaction at the edge of those BFM beads. Since the BNI-2 BFM is a low-melting nickel chromium alloy (due to the temperature depressant additions of boron and silicon in the BFM), and the 282 is a high-melting nickel chromium alloy, the BNI-2 and the 282 will have a strong affinity for each other, and some alloying will take place in a well-controlled vacuum brazing atmosphere of high...
quality, but rapid spreading of the BFM will not occur due to the oxidized surface of the 282.

Cause of Surface Oxidation

Please understand that there will always be some tiny residue of moisture/oxygen in each furnace brazing cycle, coming from the furnace walls, slight outgassing from the base metals themselves, the gel binders of the BFM, and the inherent “leak-up” rate of the furnace. Thus, I would always expect to see some oxidation of the nonplated Haynes 282, revealing itself as a darkened surface compared to the stainless steel. Thus, whenever I see such a darkened surface, I would expect that any bead of BFM paste sitting on that surface would not flow out much at all, but would tend to hold its original bead shape.

No “Titanium Activation” Reaction

It is also important to know BFM will not chemically react with stop-offs to form new compounds that become free flowing, thus contradicting the standard noninteraction of BFM and stop-offs. Nor will the titanium in the Haynes 282 “activate” a new reaction between the BFM, base metal, and stop-offs to allow the BFM to bypass the stop-off. If that were the case, we’d have seen this strang phenomenon occur many times over the past decades when brazing many of the Inconel® 700 series, since these Inconel alloys also contain additions of titanium and aluminum similar to the Haynes 282. Yes, titanium and nickel can react to form lower melting eutectics, but that will not alter the effectiveness of stop-offs in preventing BFM flow.

So the question still remains: How did the BFM “jump over” the stop-off to begin with?

Over the years, I’ve found a number of things that can hinder the effectiveness of a stop-off in its effort to prevent BFM from flowing into places it shouldn’t go. These include surface cleanliness and surface orientation, inadvertent mixing of BFM and stop-off, and relative heating rates, to name just a few. Let’s take a brief look at these.

Surface cleanliness. When a brazing stop-off is placed on top of an unclean surface (the surface may have fingerprints, machining lubricants, or oils, etc.), the stop-off may not “stick” to the surface, but may merely be floating on that dirty surface film, picking up some of that contamination and preventing the underside of that stop-off film from gripping (or reacting with) the base metal to form an impenetrable barrier to BFM flow. Instead, if the furnace atmosphere is good enough to remove some of those surface contaminants during brazing, I’ve seen rare situations where the stop-off barrier is so imperfect due to surface contamination, or poor application, that it flakes off or breaks up during heating, thus allowing the molten BFM to penetrate areas that it was not supposed to touch.

If you want a stop-off to be effective, you should, in my opinion and experience, only apply that stop-off to thoroughly cleaned and oxide-free surfaces.

Surface orientation. As you can see in Fig. 3, some people put the stop-off on a vertical surface, thinking that a molten BFM placed above the stop-off layer will not be able to go past that stop-off layer. This is erroneous thinking, and I’ve seen brazing filler metal flow by gravity right over the top of the stop-off layer and then alloy with the base metal surfaces below that.

Inadvertent interaction of BFM and stop-off. Sometimes shop personnel will place a bead of BFM paste into a groove, then place a layer (or bead) of stop-off on top of the BFM right next to the junction of the BFM and the surface to be protected — Fig. 4. The paste bead of BFM, as well as the paste bead of stop-off, will contain moisture when they are applied to the surfaces in and around the joint. This moisture must be driven off, and it is wise to do so before heating in the furnace. Otherwise, if moisture remains in those beads when they are placed into the vacuum furnace, the heat in the furnace will drive off the moisture (perhaps violently) and the vacuum itself can cause problems since the vacuum will cause the boiling point of water to decrease. Thus, the moisture in either or both of the BFM and stop-off paste beads will rapidly expand and boil off, possibly causing the beads of BFM and stop-off to shift or break apart, or even spatter. Thus, this potential shifting around the BFM and stop-off due to this moisture outgassing could be enough to allow some BFM to get through to the surface that was supposed to be protected by the stop-off. It would be interesting to run some experiments with a number of test pieces, varying the amount of moisture in either bead, the position of each bead, the drying times used, etc., to determine if this moisture might have had any effect on this problem you bring up in your question.

If a shop is using moist beads of BFM paste right next to moist beads of stop-off paste, the BFM and stop-off should be dried thoroughly prior
to placing the parts into the vacuum furnace.

**Relative heating rates of base metals.** If there is a significant mass difference between the two metal parts of an assembly being brazed, the smaller, lighter part will tend to heat up more quickly than the heavier part. Coupled with the thermal conductivity of the metals involved, there could be a significant difference in the relative heating rates of the different metallic components of the assembly.

Molten BFM's like to flow toward the heat. Therefore, if one metal gets hotter much more quickly than another in an assembly, the BFM will tend to flow toward that hotter metal surface if at all possible. In the question presented for this article, it was indicated that the Haynes 282 was the smaller, less massive component as compared to the much larger, heavier stainless component. It is therefore quite possible that when the BFM melted, it was drawn toward the Haynes alloy, and if the stop-off was broken up, or insufficient in quantity to prevent the BFM from getting onto the Haynes alloy, then the molten BFM might have been strongly drawn toward the hotter surface of the Haynes 282.

**Surface Movement**

Please understand, too, that parts move during brazing operations, especially if there is any significant mass difference between the two parts being brazed. The less massive part can actually heat up faster than the heavier part of an assembly, and thus expand or contract much more quickly than the heavier part, the extent of that difference being determined by the thermal expansion characteristics ("coefficients") of each of the metals. Thus, during the brazing operations, some parts will grow more quickly, and "lift" or "tilt" one side of the assembly relative to the other, causing parts to slip out of alignment or BFM to flow by gravity into areas it shouldn't.

**Conclusion**

From what I've described in this article, there may be a number of factors that could have worked individually, or in combo, to cause the strange phenomenon you described in your question and in the photos. There is not a clear "this is it" answer to what you presented, and each of the items I've described should be looked at in greater detail in your operations.

**Strength of joint.** You indicated the brazed parts passed your pressure testing in-house. I'm concerned that the oxidation you see on the outside of the Haynes 282 is also inside the joint to some extent, and question the "field strength" you would have for these parts. The BFM may be "gripping" the 282 surface well enough to pass inhouse pressure tests, but may not be sufficiently alloyed with that metal to form a strong enough bond for long-term service, especially if the service conditions are aggressive.

**Stop-off application.** I strongly recommend stop-off be painted onto a wider surface for protection of parts, and not just applied as a bead of paste on, or next to, the joint. Spread the stop-off layer firmly onto the surface to be protected, providing a wide path of protection.

**304 vs. 304L.** You did not indicate whether the stainless was regular 304 stainless steel or the 304L version. 304L is the alloy that should always be used when brazing or welding. Standard 304 has too much carbon in it, and can readily be "sensitized" during brazing or welding processes, potentially affecting its corrosion resistance in end-use service. That's another topic I've discussed at length in other articles on my website.