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"HOLES" IN METAL - VACUUM TIGHT FITTINGS FROM A METALLURGICAL STANDPOINT

Over the years several comments have been overheard about vacuum leaks occurring because the metal was porous or had "holes" in it. The time has come to clear the air about the possibility of this happening. Only in a few isolated instances will there be "holes" in metals that can cause leaks. Some of the instances will be discussed below.

Background

Almost all metals begin as castings. And, since most metals shrink about 3 to 6% during solidification, almost all castings contain "holes", called microporosity, that form from this contraction. Other sources of "holes" are:

1. Stresses, set up during cooling contraction, may cause internal cracks when the outside metal, cooler and perhaps restrained by design, pulls away the metal in the middle.
2. Gas reactions - several types of gas reactions occur in metals to leave gas pockets. The gas eventually may diffuse away to leave a "hole". One of these is the $\langle C + FeO \longrightarrow Fe + CO \rangle$ reaction in steel castings. Aluminum and silicon are generally added to stop this reaction - called "killing" the steel. Another reaction involves the solubility of certain gases in molten metals. For instance, liquid aluminum can dissolve 15 times as much hydrogen as solid aluminum. As aluminum solidifies, rejected hydrogen forms "holes", or porosity, throughout the casting. Most of these reactions are understood now and good molten metal fluxing, de-gassing treatments, and/or vacuum melting and casting takes care of excessive porosity in cast metals.

Even so, the metal surface of the "hole" is usually "active" - not oxidized, etc. - and will close up and weld together during subsequent fabrication. Steels do this almost all of the time.

There are other sources of "holes". If a crack, or porosity, extends to the surface, the metal can internally oxidize and will not weld together during the fabrication procedure.

Another method of "hole production" can occur even in sound material if chemical control is not maintained. The most familiar of this type of porosity is the hydrogen embrittlement caused in copper when excess CuO - present at grain boundaries - reacts with hydrogen from a brazing operation to form steam. This reaction takes place at the high temperatures of brazing when the metal is hot, so the "holes" may expand into connected porosity.

Fabrication

Castings are not generally suitable for vacuum applications because of the "through-leak" or "virtual leak" problems associated with cracks and discrete porosity. Because of this, most metals for vacuum application are fabricated by some process. The more a metal has been worked down from its cast form, the less chance there is for porosity to exist. In other words, large pieces of stock have more chances for "holes" in them than do small pieces fabricated from the same heat.

The fabrication treatment that a piece of metal has undergone should be considered before selecting vacuum hardware components. For instance, a vacuum problem that is fairly well understood, but bears repeating here, concerns a blank flange, sawn from a 12-inch diameter billet (either cast or only-so-slightly-hot-rolled). This flange will usually have the remains of centerline shrinkage (called "pipe") and will be a leaker. It would be better to cut this flange from a piece of 1/2- to 1-inch plate which has undergone considerable work - both hot and cold - to reach this stage of thickness.

Forging is an excellent way to break up and homogenize the cast ingot structure and to provide some of the best alloy from almost any metal. Porosity is closed, "pipe" is broken up and alloy properties become relatively constant throughout the piece.

On the other hand, rolled plate with strung out porosity can become a leaker if the rolled-out porosity is intercepted by two drilled holes - one hole on the vacuum side and another on the air side.

Many hard-to-melt or hot-forge super alloys are now produced by powder metallurgical processes where surface-active metal powders are cold pressed and sintered in a suitable atmosphere. This processing usually produces complete coalescence of the spheroidal particles and densities near 100% are readily achieved.

Examples and Nonexamples

There are some "nonexamples" of porosity that should be discussed. Too often a leak checker will be quick to blame the "holes" in a piece of metal when (1) the seal groove has an embedded hair or piece of dirt in it and a leak results, or (2) faulty brazes or cracked welds are the cause of the leak. A "nonexample" was a large stainless-steel blank flange, advertised as a leaker, which came to my attention some time ago. Someone had etched the surface, saw the "stringers" of ferrite present in most stainless steels, and promptly announced he had shown the presence of "holes" in the metal. Again the microscope showed the blank flange had a bad seal groove.

But the man could never be convinced, because for years he had heard stories of "holes" in metals.

I have talked to some of the top metallurgists in the country on this problem and their first look is one of incredulity. They cannot understand why people still believe this. However, they do recognize the presence of "pipe" in cast metals and have measured vacuum leaks over four feet long in centerline "pipe" in copper ingots - but not in wrought copper.

Offer

For some three to four years I have extended a standing offer to examine any leaking vacuum fitting for several people who have had these problems at SLAC. I haven't been shown a "hole" yet, although proponents of "holes" in metals still claim they exist.

Metals, except where noted above, do not have "holes".