

2013 UTSR Gas Turbine Industrial Fellowship Program

Gas Only IPI Braze Failure

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Introduction

The Greenville office of Woodward, Inc. primarily focuses on fuel delivery systems and ignition for power generation gas turbine engines. Woodward works with many types of unique materials from super alloys to ceramics. Because of this, Woodward Greenville employs multiple different methods of material joining : TIG welding, braze, and EB welding. Often times these joining processes are iterative solutions to determine the exact process parameters, and even after many tests, joints might still continue to fail. This summer, the company was having a large dropout rate with a specific braze on the Gas Only lance, which led to a systematic investigation to the cause of the failure

Background

The specific braze joint that had been exhibiting a large dropout rate was a part of the Gas Only lance product line at Woodward. The part is used to inject swirled gas into the combustor. Referring to Figure 1, the pressured gas is introduced into the part in the back of the flange (left) and is ejected out of the atomizing tip (right) into the rest of the combustion system.

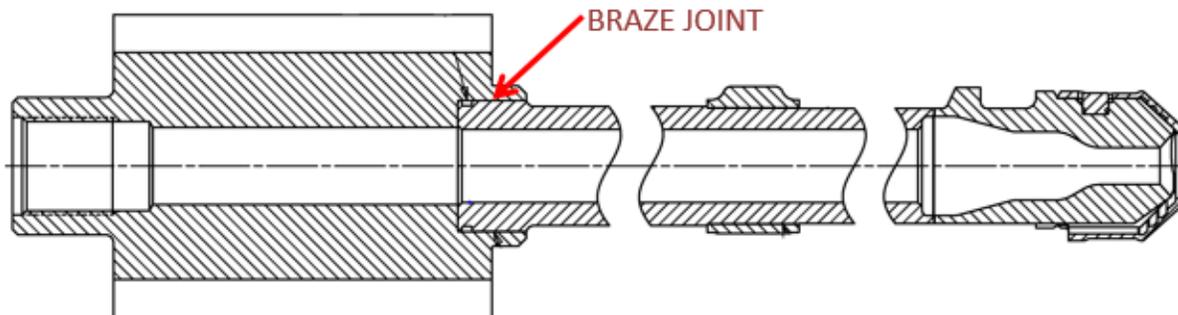


Figure 1: Gas Only IPI Braze Joint Failure

This part contains multiple weld and braze connections. However, the joint in question is the connection interface between the nickel-plated 321 SS flange and the Hastelloy X oil tube, as is designated by the red arrow in Figure 1. Figure 1 also illustrates the location of the vacant groove where the braze filler material will reside prior to the brazing process.

Due to the geometry of the joint, it is expected that the majority of the braze filler material would exhibit capillary action towards the atomizer tip. The filler material should be visible to the naked eye after a successful braze joint. However, this was not the case for about 20% of the parts that have undergone the process. The filler material for these parts was not succumbing to the capillary process leaving noticeable voids for the visual inspection. Figure 2 helps illustrate this issue.

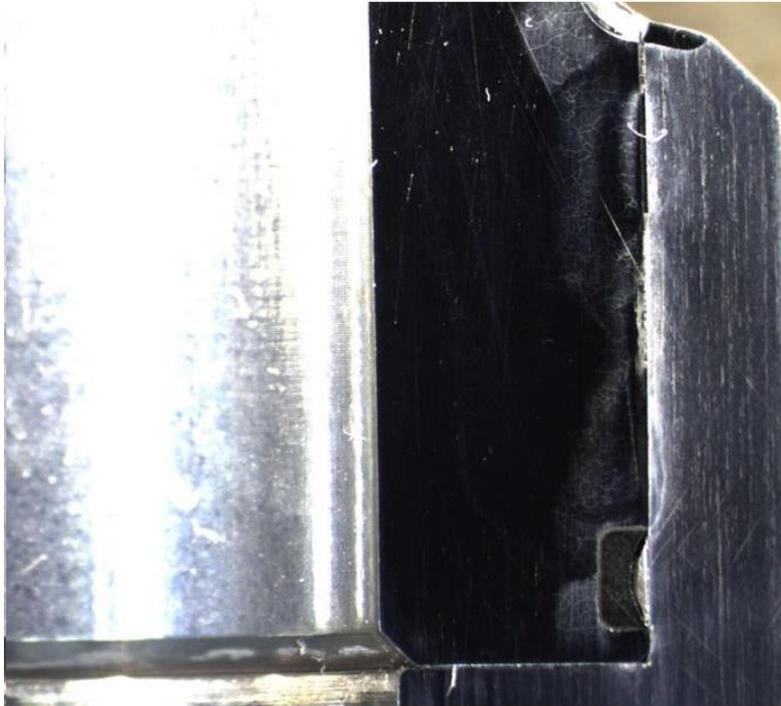


Figure 2. Post-braze visual inspection failure

This specific part underwent post braze corrective actions by being additionally braze from the external surface (top in Figure 2). However, if one looks closely they can see the extent of the capillary action from the original brazing process, which only extended about halfway. Another large issue from the braze joint is a lack of wetting to either the Hastelloy X tube or the nickel plated 321 stainless steel flange. The gold braze material appeared to not wet at all to the flange, and it appeared to only partially wet to the tube. This is also evident in Figure 3.

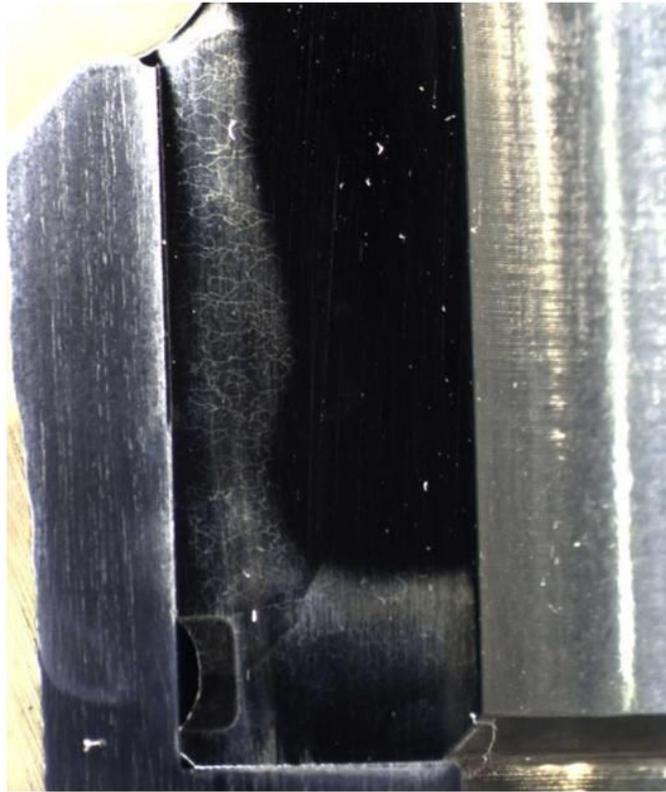


Figure 3. GO IPI braze failure joint

One can see that the material only wetted a few millimeters into the Hastelloy X tube, and didn't wet at all to the external 321SS flange. Figure 4 shows a relatively clean surface of the flange braze surface. Clearly, the braze material did not wet nor adhere to this surface.

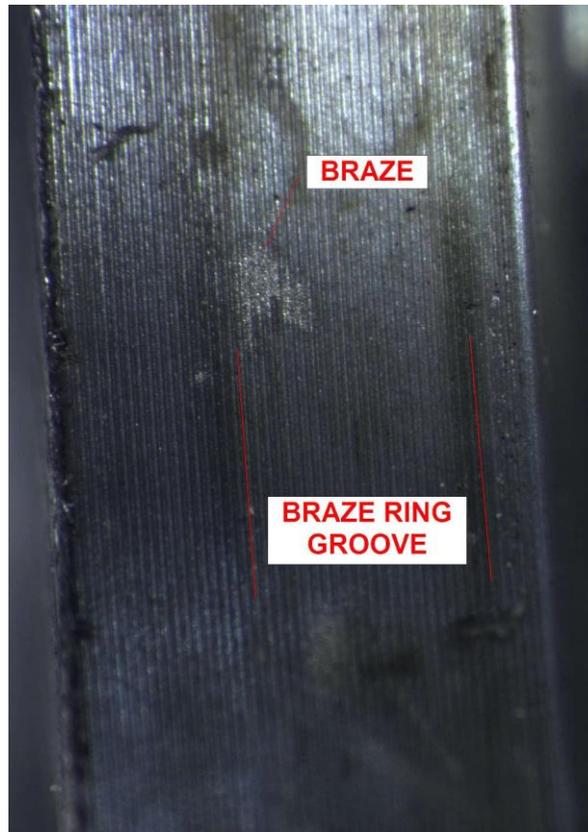


Figure 4. Flange braze surface

The large amount of braze material remaining in the braze groove is additionally indicative of the lack of capillary action and wetting present in this specific braze. Both Figure 2 and Figure 3 show this. Ideally, this groove should be entirely evacuated indicating that all of the filler material is used and that the interface has its optimal strength.

Because of the above observations, the failed joints would not have the necessary strength handle application environment of high temperature and high stress. The root cause of these problems can be anything to incorrect tolerances to contamination in the braze joint preparation.

Preliminary Investigation

In order to curb the undesirably high dropout rate of this braze joint, it is important to understand the root cause of why these joints are failing. A systematic approach to investigating the joint can be taken by adhering the following guide (Figure 5) to braze joint failures.

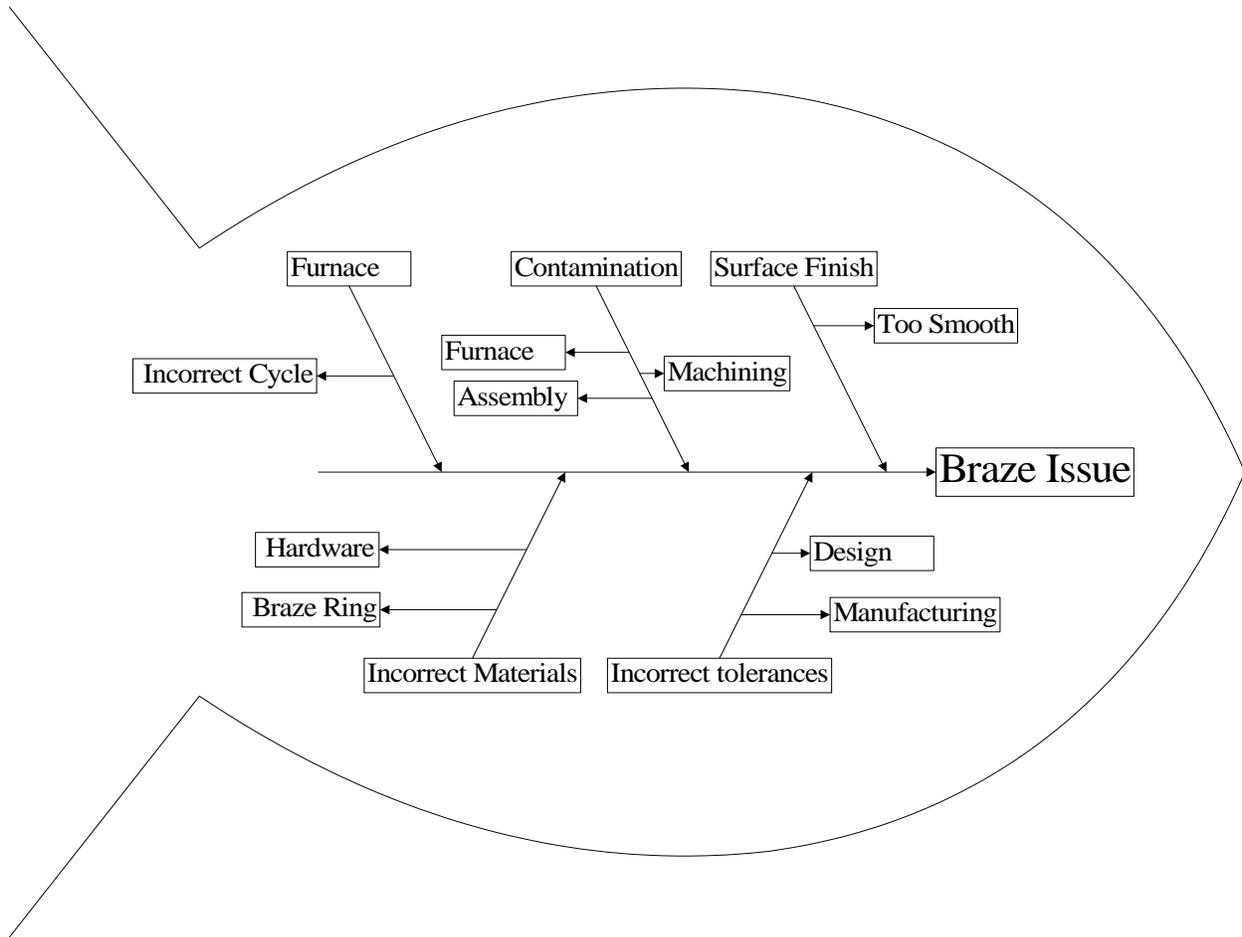


Figure 5. Braze failure fishbone guide (Narasimhan & Jones)

Some of the potential causes can be ruled out by ensuring the braze process parameters are correct: heat temperatures, soak time, filler material volume, and braze joint tolerances. However, the other parts of the investigation are a bit more in depth.

It is possible that the samples that had failed were exposed to contamination prior to brazing. Certain contaminants might affect the brazing process in different ways. If, for example, any amount of excess sulfur (lubricant, hand creams, etc.) present in the braze joint, it may cause an embrittlement of the nickel plating on the flange (Schusteritsch & Kaxiras, 2012). If this were the case, it would dramatically alter the brazing chemistry and could require much different soak temperatures, soak times, or other parameters. This however would be very difficult to test for, but could be ensure that the proper cleaning techniques prior to brazing are adhered to in a rigorous manner.

It is also possible that the surface finish of the nickel plating is too smooth, which would limit the capillary effects of the braze material. However, this is unlikely considering the surface structure illustrated in Figure 4. One can see the machined grooves on that surface, which should facilitate the viscous flow of the filler material.

Finally, it is possible that the material composition of the braze rings were not correct. The material may have violated the existing material specification, or braze rings may have been mixed up. In either case, it is important to determine that the materials used in the braze process were correct before any more in depth and rigorous investigation is undertaken.

Braze Material Investigation

It was important to determine that the materials used in the brazing process were in fact correct. Oxidation of existing rings, potential mix-up with other braze rings, and incorrect specifications from the supplier would affect the brazing process dramatically. The specified braze ring should adhere to the AMS 4787 specification (82% gold and 18% Ni with only trace contaminants) (The Prince and Izant Company, 2014). The un-brazed rings in the stockroom and post braze filler material were to be tested relative to the AMS standard, which is described in Figure 6.

NOMINAL COMPOSITION	Au:	82.0% +/- .5%
	Ni:	Balance
	Total impurities:	0.15% max
This alloy is also available in a Vacuum Tube Grade (VTG) having the following impurity limits:		
	Zn:	.002% max
	Cd:	.002% max
	P:	.002% max
	Cu:	.05% max
	Ag:	.05% max
	C:	#2 on ASTM button test, or better
	Pb:	.002% max
	Others each:	.005% max
	Max total others:	.010% max

Figure 6: AMS 4787 material specification

Pre-Brazed Ring Material

The existing rings in the stockroom were tested to ensure that the supplier was in fact providing accurate specifications and that there has not been and errors or mix-ups in restocking operations.

Methodology

Considering the fact that these rings have not been brazed yet, testing material composition was significantly easier that measuring that of post-brazed rings. The materials were



tested using the hand-held x-met gun, which employs energy dispersive x-ray spectroscopy.

Results

It was determined that every un-brazed ring did in fact have the correct material as specified by AMS 4787. All rings also were the correct geometry as specified by the part number.

Post-Braze Ring Material

It is important to determine that the ring used in the previous brazing process were using the correct material. Considering the complication that the material is surrounding by other materials it becomes much harder to test only the braze material and not the surrounding material; using the x-met gun would be an option because it does not have a small enough resolution testing area.

Methodology

It was suggested to test the material using a scanning electron microprobe analysis through an external company, Lucideon Laboratories. The SEM process would be able to accurately measure the material composition at a focused location. The excess material residing the groove ring could be prepared for testing with SEM microprobe. The bottom part in Figure 7 shows the residual material to be tested.



Figure 7. Failed braze material

The part was mounted in an epoxy substrate and polished as shown in Figure 8.



Figure 8. Polished and mounted post braze material

Once mounted, the sample was tested using the electron microprobe which also utilizes energy dispersive x-ray spectroscopy.

Results

Figure 9 shows the existing spectral lines present in this specific sample.

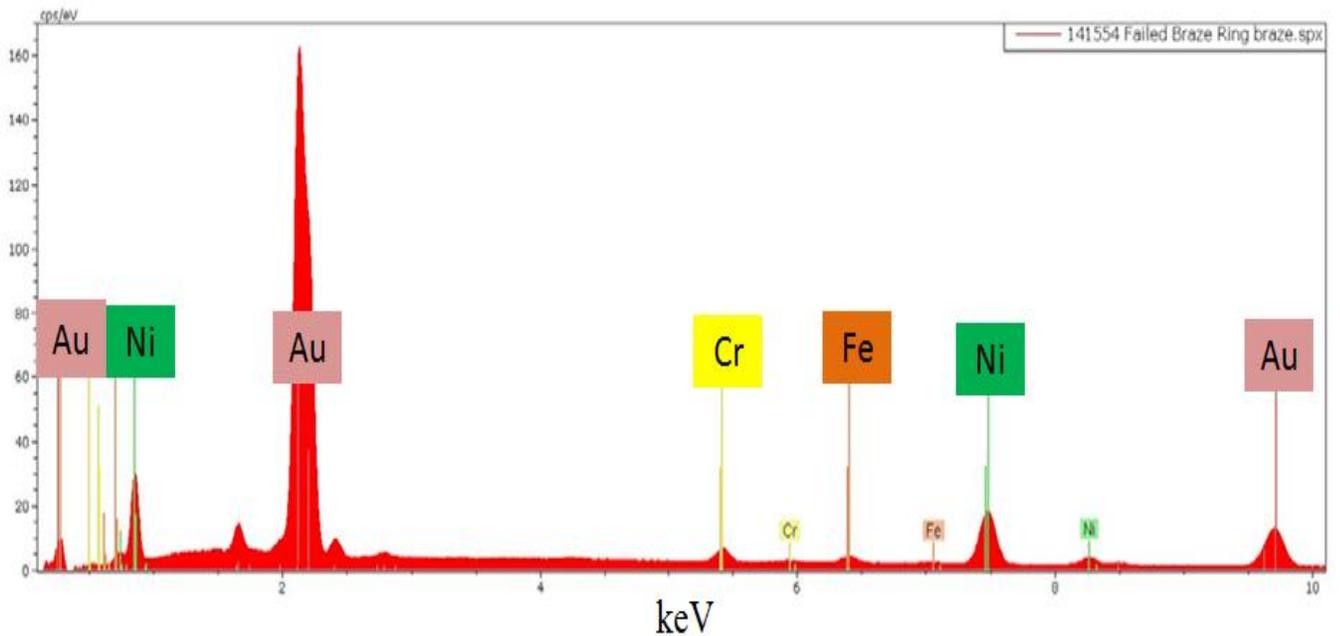


Figure 9. Material energy spectrum measured using microprobe

The standardless, semiquantitative weight percent results are presented in Figure 10.

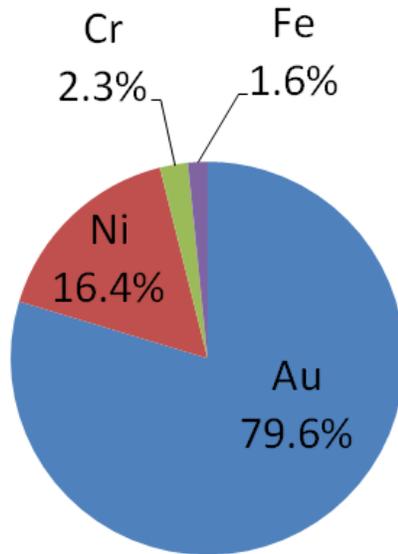


Figure 10. Material composition by weight

When comparing these results to the AMS standard (Figure 6), it is clear that these results don't entirely obey specified chemical compositions; there are significant amounts of chromium and iron and a diminished quantity of nickel. However, it is important to note that the braze material had partially wetted with the Hastelloy-X tube, which contains significant compositions of chromium and iron explaining this discrepancy. See Figure 11.

Nominal Chemical Composition, Weight Percent									
Ni	Cr	Fe	Mo	Co	W	C	Mn	Si	B
47*	22	18	9	1.5	0.6	0.10	1*	1*	0.008*
*As balance		*Maximum							

Figure 11. Hastelloy X chemical composition

Conclusions

After testing the un-brazed rings and the post-braze material, it was determined that no errors were made on the part of the supplier nor the braze joint assembly technicians. The braze joints were prepped to specification. This indicates that the explanation of the high drop-out rate is elsewhere in the design of this weld. Further investigation should be undertaken towards other aspects listed in the Figure 5: incorrect tolerances, incorrect braze cycles, or reinvestigate surface finish.

Specifically, reinvestigation of the amount of filler material should be determined. It is a possibility that the determined amount of the filler material is a bit shy of the actual



required amount, causing welds on the low side of the tolerances to not have sufficient contact with the flange. It is also a possibility that the braze cycles are not allowing a sufficient amount of soak time to allow for proper wetting of the braze filler material.

It is recommended that any further braze attempts on this joint should be fully documented: measure each part's actual tube OD, flange ID, and braze material volume. Comparing this information with the success of the weld, one could determine if the tolerances are in fact a driving factor for the failures.

References

Narasimhan, J., & Jones, E. (n.d.). Reduction of Variation in a Welding Process using Operation Six Sigma Methodology. *University of Nebraska*.

Schusteritsch, G., & Kaxiras, E. (2012). Sulfur-induced embrittlement of nickel: a first-principles study. *Modeling and Simulation in Materials Science and Engineering*.

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