Influence of Gap Clearance on Brazing Joint Strength for Ni and Fe Based Filler Metals

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Abstract

The effect on brazing joint strength as gap clearance varies has been evaluated in this report. It is a known phenomenon that some brazing filler materials form stronger bonds when the gap clearance decreases, and this investigation adopts a practical approach at evaluating some of the modern Ni-based filler metals to determine if - and how much - strength increases as gap clearance decreases for those materials. Preliminary results show that joints brazed with the Ni-based fillers: BNi-2, BNi-5, BNi-7 seem to increase in strength as gap clearance goes under 50-60µm. This increase in strength may be caused by changes to the microstructure which are known to occur in those gap clearance regions. It has been confirmed in this report that at least for BNi-2, there is a significant shift in failure mode of the brazing joint as the microstructure changes. For large gaps (<100µm) the fracture occurs in the brittle centreline of the joint, and for smaller gaps (~50µm) a sort of delamination occurs in the interface between the base material and the filler metal.

No strength increasing effect has been observed for the filler metals Ni613 and BrazeLet® F300, however that is likely because there have been no tests at low enough gap clearances yet. More data is being gathered and analysed during the spring to compliment the preliminary results shown in this report.

Introduction

There are many different types of possible joint configurations when brazing components or test specimens. In practice, the joints produced in a component are often very complex and thus it is difficult to know the strength of the bond without performing some sort of destructive testing.

Certain rules of thumb have been established by the brazing community, such as the example for the single lap shear joint: “if the thickness of two parts to be joined is: ”t”, then a brazing overlap of “6t” will create a bond stronger than the materials being joined”. Rules of thumb can be very helpful at times, but sometimes a deeper knowledge of how different parameters affect joint strength may be advantageous. This report will attempt to explain the influence of gap clearance on joint strength specifically in a butt joint configuration.

A lot of work has already been put into characterizing the influence of gap clearance on joint strength, where a notable example would be the results from Handy and Harman Laboratories in the 1930’s as is discussed by Dan Kay in his article: “The famous joint strength vs joint clearance chart” [1]. This chart is shown in Figure 1 below.

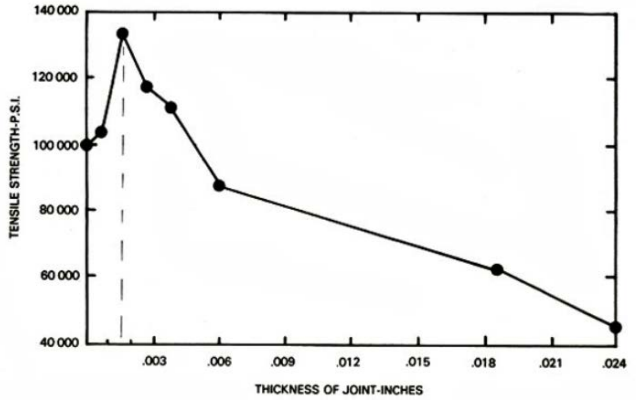


Figure 1. Joint clearance vs joint strength [1].

There’s a peculiarity with the graph above which is worth mentioning, specifically the left part, which suggests a drop-off in joint strength as gap clearance becomes very small (somewhere below 0,002in / 50µm). As is discussed by Dan Kay in his article, this is likely not true in the sense that it is not gap clearance directly that causes a decline in strength. There are other parameters at play, such as the increasing influence on strength from voids and impurities as gap clearance decreases.

Either way it is an accepted notion in the brazing community that strength does indeed increase as gap clearance decreases, regardless of any potential disagreements concerning the cause. The work in this paper has been aimed towards re-evaluating this phenomenon with a practical approach for the (relatively speaking) newer Ni-filler metals: BNi-2, BNi-5, BNi-7 and Ni613 as well as Höganäs patented iron based alloy BrazeLet® F300. These materials add another level of complexity to the problem, as Ni-filler metals tend to form brittle eutectic centerlines in certain gap clearance intervals.

Material and Method

In this report, joint strength was investigated according to the standards in Table 1.

Table 1. Standards used in sample preparation and tensile testing.

EN10002-1 **Metallic materials – Tensile testing –** Part 1: Method of test at ambient temperature
EN12797 **Brazing – Destructive tests of brazed joints**

5 materials were evaluated in this investigation, see Table 2.

Table 2. Filler metal materials evaluated in this report (ISO 17672:2016 - Brazing - Filler metals).

Höganäs	AWS	ISO	Composition
BrazeLet® Ni2	BNi-2	Ni620	Ni82CrSiBFe
BrazeLet® Ni5	BNi-5	Ni650	Ni71CrSi
BrazeLet® Ni7	BNi-7	Ni710	Ni76CrP
BrazeLet® Ni613*	-	-	Ni60CrPSi
BrazeLet® F300	-	-	Fe39CrNiCuPSi

*Ni613 is a licensed product, patented by Fukuda Metal Foil & Powder co.,ltd.

Test specimen

The chosen test specimen geometry is the butt joint [3]. Two halves made from 316L stainless steel were brazed together with a specific gap clearance. Two different ways were used to reach specific gap clearance. The first is as recommended by EN10002-1, the second is Höganäs' own adaptation to the method in order to improve control over gap clearance.

1. Machined steps.
   30µm and 100µm steps were used.

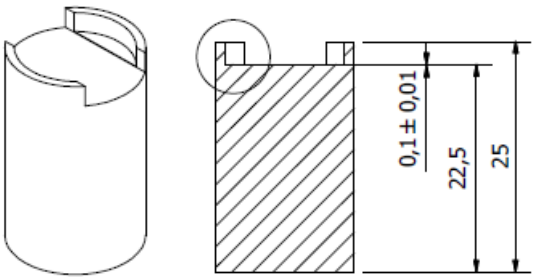


Figure 2. Bottom half of test specimen.

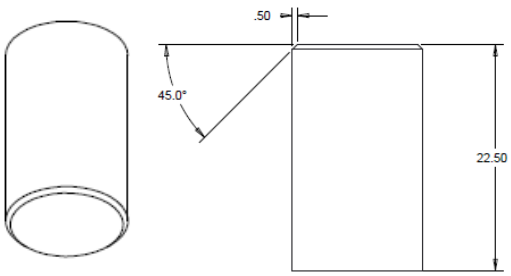


Figure 3. Top half of test specimen.

To illustrate the difficulties with machining steps for determining the gap clearance, Figure 4 and Figure 5 show a 30µm and 100µm step respectively, as cut and observed in an optical microscope. As the step becomes smaller, it becomes increasingly difficult to manufacture due to tolerances in the machining operation. In order to produce test specimens with even smaller gap clearances, another method, which is described below, was used.

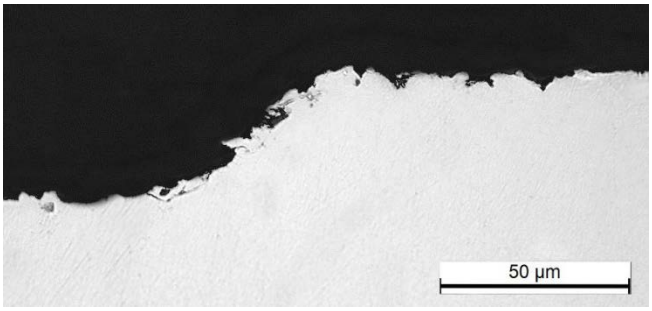


Figure 4. 30µm machined step.

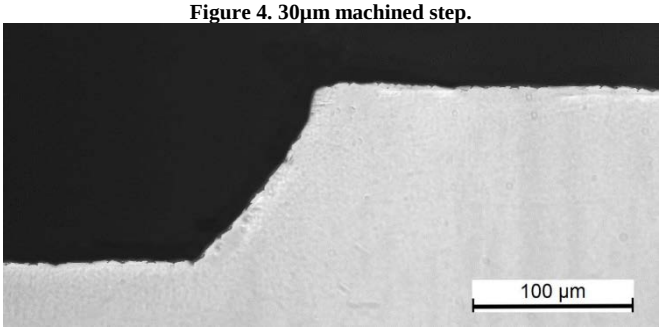


Figure 5. 100µm machined step.

2. Wire displacers made from 316 stainless steel. Stainless wires/thread were used as spacers to reach specific gap clearance. The bottom piece shown in Figure 6 did not have a step machined.

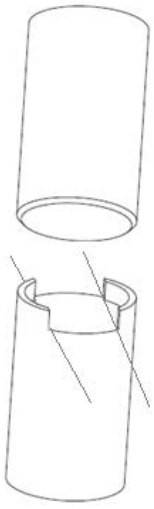


Figure 6. Gap clearance achieved through the use of thin (316 stainless steel) wire inserted between the two test pieces.

Table 3 shows the different thickness of wire used.

Table 3. Wire thickness used to reach specific gap clearances.

#	Wire thickness [µm]
1	"0" (no wire)
2	25µm
3	41µm
4	78µm
5	300µm

Specimens were placed in a fixture and brazing filler metal was applied as a paste as shown in Figure 7. The paste contained powder particles sieved to <63µm.



Figure 7. Sample prepared for brazing. Paste applied outside the gap between the pieces.



Figure 8. Sample after brazing.

4 test specimens were made per material and gap clearance.

Brazing process

Brazing was performed in a vacuum furnace under high vacuum (~10^{-5} mbar) at the recommended brazing temperature for each filler metal:

Table 4. Summary of tested filler metals and brazing temperatures used.

Filler metal	Brazing temperature
BNi-2	1050°C / 1922°F
BNi-5	1150°C / 2102°F
BNi-7	970°C / 1778°F
Ni613	1090°C / 1994°F
F300	1100°C / 2012°F

The temperature ramp was 9°C/minute and a 30 minute hold at 450°C was implemented to guarantee that the binder in the paste had burnt off completely. Indirect cooling in vacuum (switched off heating elements) was used in all tests.

Tensile test

After brazing, the assembly was machined to a tensile rod according to the drawing in Figure 9 and tested axially in a Zwick/Roell 10kN tensile testing machine. The tests were performed in room temperature according to EN12797 [4]. The diameter of the thin section has been changed to 4.0mm from 4.5mm (4.5mm is recommended by EN12797). This change was made to guarantee that the tensile testing machine would be capable of fracturing the specimens.

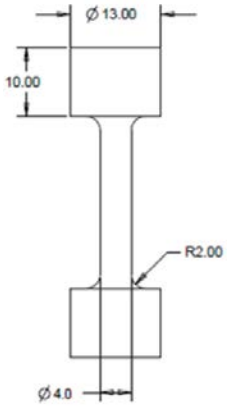


Figure 9. Tensile test specimen drawing.

Before tensile testing, gap clearance was evaluated non-destructively in a Lecia DM6000 light optical microscope. The gap clearance of each individual specimen was recorded and corresponded against the ultimate tensile strength of that specific tensile test.

Lastly, the fracture surfaces were investigated in an attempt to determine the mode of failure in each joint. The tested tensile specimens were fitted back together using Loctite 407 super glue - then mounted, polished and observed in a Leica DM6000 light optical microscope.

Homogeneous stainless steel 316L reference

Homogeneous 316L tensile test specimens were also produced. The geometry was the same as for the brazed samples (see Figure 9). These specimens were used to compare the strength of brazed samples to the actual strength of the base material.

Micro hardness measurements

As a complimentary investigation, Vickers hardness was measured using a Matsuzawa MMT-7 micro hardness tester to show the large difference in hardness and thus brittleness between different phases in the microstructure of the materials. Large gaps (>100µm) were tested across their thickness. Indentations were made in 40µm intervals.

Results

The following diagrams show strength vs gap clearance for each individual test specimen, separated material by material.

Strength vs gap clearance

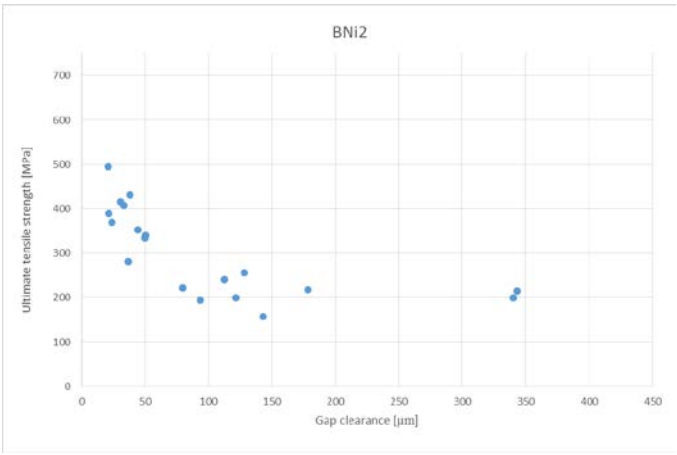


Figure 10. Strength vs gap clearance for BrazeLet® Ni2.

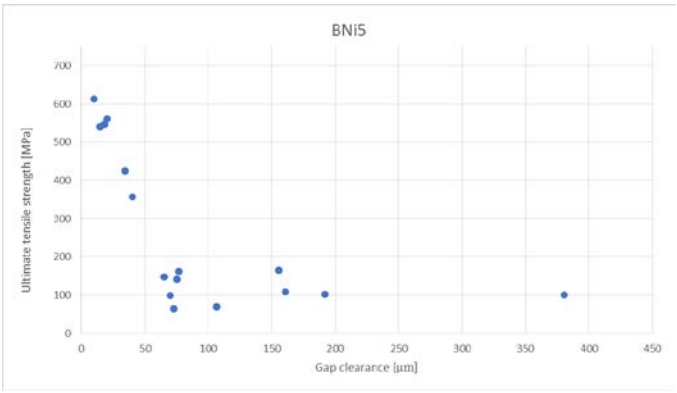


Figure 11. Strength vs gap clearance for BrazeLet® Ni5

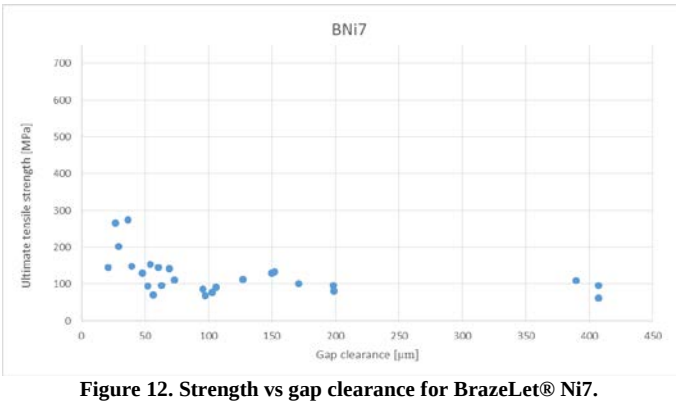


Figure 12. Strength vs gap clearance for BrazeLet® Ni7.

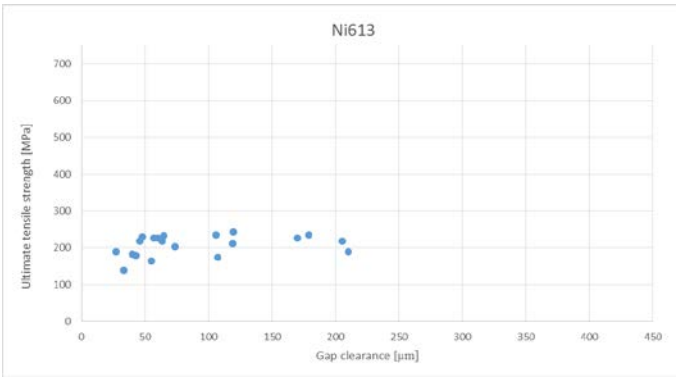


Figure 13. Strength vs gap clearance for BrazeLet® Ni613

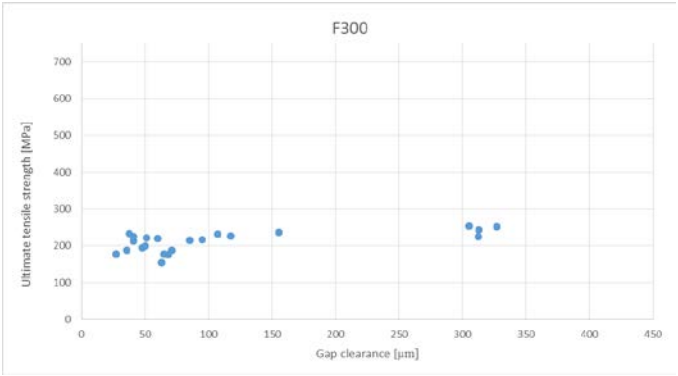
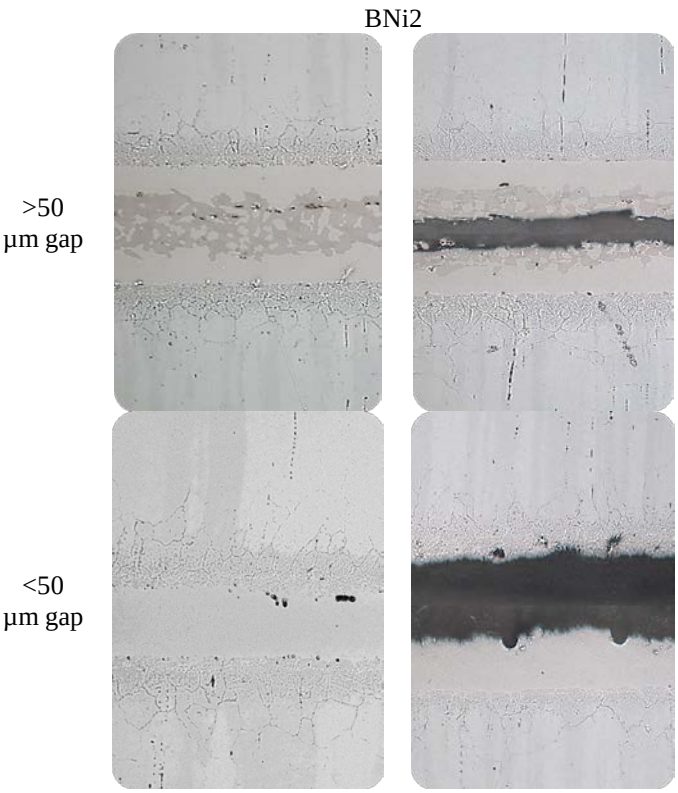


Figure 14. Strength vs gap clearance for BrazeLet® F300.

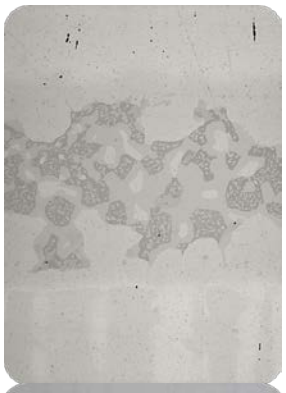
Fracture surface investigation

Different modes of failures were observed depending on the microstructure of the brazing joint.



BNi5

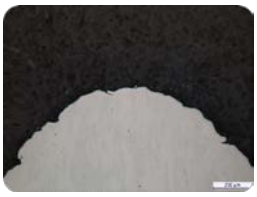
>50 µm gap





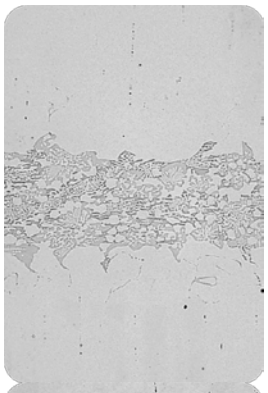
>50 µm gap





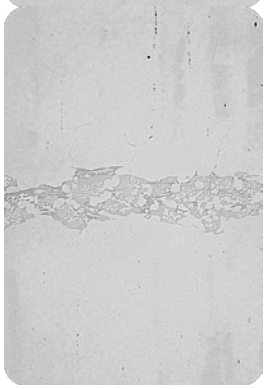
F300

>50 µm gap





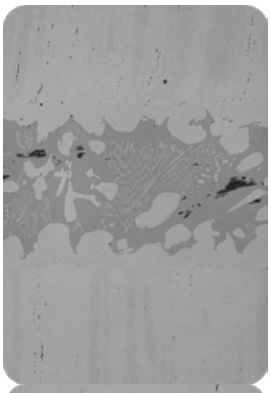
>50 µm gap





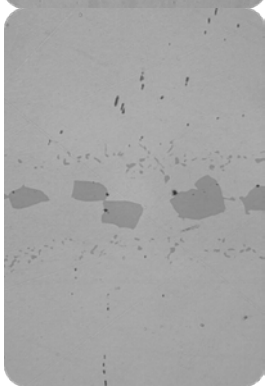
BNi7

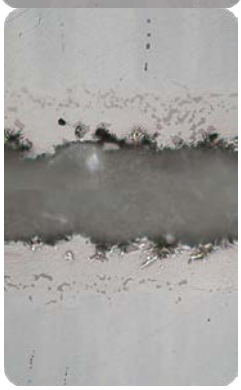
>50 µm gap





>50 µm gap





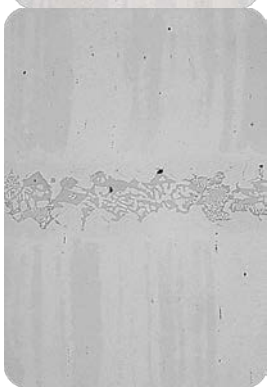
Ni613

>50 µm gap





>50 µm gap





Stainless steel 316L strength

The homogeneous tensile test specimen strength is shown below in Table 5.

Table 5. Homogeneous 316L tensile test results.

	Tensile strength [MPa]
As received (cold drawn and machined)	707
As received + heat treated in a brazing cycle at 1100°C	607

Micro hardness

The results from the micro hardness tests show that there is a significant difference in hardness for the different phases. Figure 21 shows the microstructure of Ni613 in a large gap (>50µm) and the occurrence of 3 visually distinctive phases. Even by only looking at the images from the hardness test (Figure 22 and 23), it is obvious that there is a difference in brittleness of the phases marked 1 and 3. Clearly visible cracks have propagated from the edges of the indentation tool for the brittle phase.

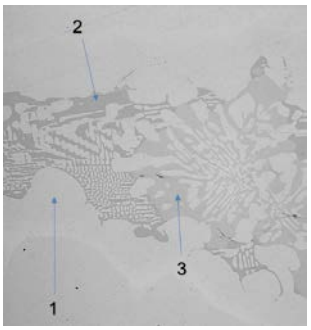


Figure 15. Microstructure of large gap (>50µm) Ni613.

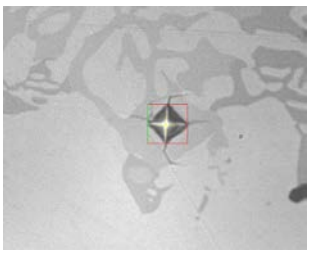


Figure 16. Indentation mark of phase 3 as shown in Figure 21.

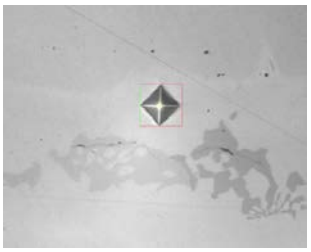


Figure 17. Indentation mark of phase 1 as shown in Figure 21.

A hardness profile of all the evaluated materials in this investigation is shown in Figure 24 below. It is clear that all the materials form hard phases in the centreline, to some extent, when the gaps are large (>50µm).

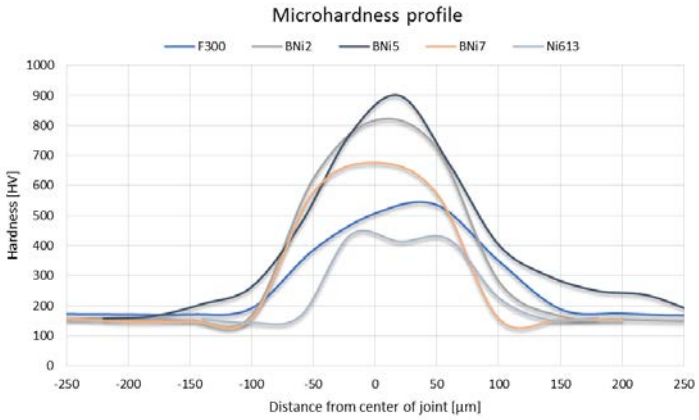


Figure 18. Microhardness profile for the tested materials BNi-2, BNi-5, BNi-7, Ni613 and F300.

Conclusion

BNi2: **200-250MPa** when gap clearance is **above 50µm.**
300-500MPa when gap clearance is **below 50µm**.
Likely tied to a change in microstructure.

BNi5: **100-200MPa** when gap clearance is **above 50µm.**
350-600MPa when gap clearance is **below 50µm.**
Likely tied to a change in microstructure.

BNi7: **80-120MPa** when gap clearance is **above 50µm.**
150-280MPa when gap clearance is **below 50µm.**
Likely tied to a change in microstructure.

F300: **180-240MPa** regardless of gap clearance.

Ni613: **170-240MPa** regardless of gap clearance.

Discussion

A substantial increase in strength was observed for test specimens brazed with BNi2, BNi5 and BNi7 when gap clearance went below 50µm. The strength observed for specimens brazed with BrazeLet® F300 and Ni613 stayed at a consistently relatively high level regardless of gap clearance, and did not increase for low gaps. Where strength increase was observed, it corresponded well with changes in the microstructure of the brazing joints. For BNi2 and BNi5 joints, the change in microstructure also seems to lead to a change in fracture mode. In real life applications it may prove challenging to achieve low gap clearances without significant force being applied on the joint during brazing.

References

[1] The famous joint strength vs joint clearance chart – Dan Kay - https://vacaero.com/information-resources/vacuum-brazing-with-dan-kay/1300-the-famous-joint-strength-vs-joint-clearance-chart.html. Time of source: 2018-01-11.
[2] ISO 17672:2016 - Brazing - Filler metals
[3] EN10002-1 Metallic materials – Tensile testing – Part 1: Method of test at ambient temperature
[4] EN12797 Brazing – Destructive tests of brazed joints