Effect of Brazing Atmosphere on the Corrosion Resistance of Ferritic Stainless Steels Brazed with Ni- and Fe-base Filler Metals

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Ferritic stainless steels are gaining interest due to the combination of low cost, low thermal expansion and good high temperature scaling resistance compared to the commonly used austenitic stainless steels. These materials are of special interest for exhaust gas system components in gasoline cars, where the service temperatures are higher than for diesel cars. Previous research on the corrosion resistance of brazed ferritic stainless steel components have focused largely on vacuum brazed components, while the focus on belt furnace brazing has been limited. The presence of nitrogen in the brazing atmosphere has been found to affect the corrosion resistance of the base materials and filler materials in studies with austenitic stainless steels, but the effect on ferritic stainless steels has not yet been studied. In this investigation, AISI 430 and AISI 441 test samples were brazed with the common Ni-base brazing filler metals BNi-2, BNi-7, BrazeLet® Ni613 and Höganäs Fe-base brazing filler metal BrazeLet F300. Specimens were brazed in three different conditions: Vacuum furnace brazing, 90 %N_2/10 %H_2 belt furnace brazing and 100 % H_2 belt furnace brazing. The effect of the brazing atmosphere on corrosion resistance was evaluated by VDA 230-214 K.2.2 testing and SS-EN ISO 16701 salt spray testing. Significant differences in corrosion resistance were observed for the tested brazing filler metals, with BNi-2 experiencing the most severe corrosion attack. The brazing atmospheres were found to affect the brazed joint corrosion resistance mainly by affecting the base material corrosion resistance, where nitrogen in the brazing atmosphere was found to have a detrimental effect on the corrosion properties. AISI 430 was sensitised as a result of the brazing cycle, particularly in the belt furnace-brazed specimens. With the exception of BrazeLet Ni613, none of the brazing filler metals showed an effect of brazing atmosphere on corrosion resistance.

1 Introduction

Ferritic stainless steels are gaining increasing interest for brazed components due to the combination of low cost, low thermal expansion and good high temperature scaling resistance, compared to the commonly used austenitic stainless steels. The use of ferritic stainless steels is growing particularly for industrial and automotive heat exchanger applications, where these properties are beneficial. Further, Exhaust Gas Recirculation (EGR) coolers are becoming more common also in gasoline and hybrid gasoline engines, to meet more stringent emission standards. As the temperatures in gasoline engines are generally higher than in diesel engines, the ferritic stainless steels provide a benefit for such applications.

Although there has been several good research contribution within the field of ferritic stainless steel brazing in the recent years, the amount of data available is still very limited compared to the more commonly used austenitic stainless steels. The previous contributions have mainly been focusing on the brazed joint microstructures, strength properties and differences in diffusion behaviour of different elements in ferritic stainless steels compared to austenitic stainless steels [1-4].

The ferritic stainless steels have also shown to be subject to grain growth when subjected to high-temperature brazing cycles. Grain growth in ferritic stainless steels negatively impact mechanical properties such as strength and ductility, but the effect on corrosion resistance is less evident. Grain growth reduces the effective grain boundary area exposed to the corrosive media, and increases the corrosion resistance of the base material slightly [5].

The effect of the brazing atmosphere on the corrosion resistance of ferritic stainless steels has not been studied in detail previously. This is of interest as the potential combination of more cost efficient ferritic stainless steel base materials and continuous belt furnace brazing, could be attractive to for example EGR cooler manufacturers from a cost and productivity perspective. Aida et al. studied the differences between using nitrogen and argon as the process gas in continuous belt furnace brazing, but the corrosion testing performed was limited to salt spray testing, and no difference in corrosion resistance was observed [6]. They did however find that brazing in nitrogen atmosphere significantly increased the spreading ratio of Ni613 on AISI 430, indicating nitrogen affects the base material surface, but the root cause of this effect was not studied in detail in their work.

Recently, Fedorov et al. have studied the influence of nitrogen in the brazing atmosphere on austenitic stainless steels, and found that both the brazing filler metal and the base material are significantly enriched by nitrogen as a result of the brazing process [7]. Their further trials revealed that the nitrogen content affects the corrosion resistance of both the base material and the brazing filler metal [8]. It is necessary to examine whether the same effects are seen for the case of brazing ferritic stainless steels.

To reflect the internal conditions in EGR coolers, VDA 230-214 corrosion testing is relatively common [9]. This has been used to test the corrosion resistance of austenitic stainless steel joints, [10, 11], but also recently for AISI 430 ferritic stainless steel in the work by Tillmann et al. where joints brazed with BNi-2 and Ni-Cr-Si-P-B brazing foil was compared [12].

2 Experimental Procedure

2.1 Brazing filler metals and base material

The brazing filler metals investigated in this work are listed in Table 1. They include the most commonly used Ni-base alloys BNi-2 and BNi-7 along with BrazeLet® Ni613 and the Fe-base brazing filler metal BrazeLet F300.

Table 1. Brazing filler metals evaluated in this report

Product name	AWS A5.8	ISO 17672 [13]	Composition	Brazing temperature
BrazeLet BNi2	BNi-2	Ni620	Ni82CrSiBFe	1,050 °C / 1,922 °F
BrazeLet BNi7	BNi-7	Ni710	Ni76CrP	980 °C / 1,796 °F
BrazeLet Ni613(1)	-	-	Ni60CrPSi	1,100 °C / 2,012 °F
BrazeLet F300	-	-	Fe39CrNiCuPSi	1,120 °C / 2,048 °F
Note 1: Ni613 is a licensed product, patented by Fukuda Metal Foil & Powder co. Ltd.				

The base materials tested was AISI 430 (W.No. 1.4016) and AISI 441 (W.No. 1.4509) ferritic stainless steel, supplied as rolled plate material. AISI 441 is an upgraded version of AISI 430, with slightly higher Cr content as well as being stabilized by Ti+Nb to prevent sensitization. The chemical composition of AISI 430 and AISI 441 is shown in Table 2.

Table 2. Chemical composition specification for AISI 430 and AISI 441. All values are in wt%.

Grade	Fe	C	Mn	Si	P	S	Cr	Ni	Ti	Nb
AISI 430	Bal.	< 0.12	< 1.00	< 1.00	< 0.04	< 0.03	16.0-18.0	< 0.75	-	-
AISI 441	Bal.	< 0.03	< 1.00	< 1.00	< 0.04	< 0.015	17.5-18.5	-	0.1-0.6	0.3+3C-0.4

2.2 Test specimen preparation and brazing

Brazing paste was applied as dot at one end of the test specimens by manual dispensing. Applied weight was controlled to be 0.20 g. Vacuum brazing was performed in a Carbolite tube vacuum furnace under high vacuum (~ 10^{-5} mbar) at the standard recommended brazing temperature for each filler metal. These temperatures are summarised in Table 1. The temperature ramping speed was 9 °C/min, and a 30-minute hold at 450 °C was implemented to ensure complete burn-out of the binder. The time at the brazing temperature was 30 minutes. Natural cooling in high vacuum was used for all samples.

Belt furnace brazing was performed in one of Höganäs' belt furnaces. The furnace consists of six heating zones, where the last four are the brazing zone. Zone 1 and Zone 2 temperatures are set as a function of the brazing temperature set in Zone 3 - 6. The belt speed was set to 50 mm/min through Zone 1 and 2 to reduce the heating speed slightly and manually increased to 100 mm/min when the specimens entered the brazing zone (Zone 3-6) to achieve a time at brazing temperature of 15 minutes.

2.3 ISO 16701 Salt Spray Corrosion Testing

The test specimens were subject to salt spray corrosion testing to represent external conditions for exhaust-gas system components, as well as other heat exchanger applications, which can be subject to humid, salt-containing environments. There are many different corrosion test standards for salt spray testing available. Based on the comparative study of the different testing methods [14], a method with humidity cycling combined with salt spraying was selected with the ISO 16701 test standard [15]. The salt spray solution was prepared from dissolving sodium chloride in demineralised water to a concentration of 10 g/l (± 1 g/l). The pH of the solution was adjusted to be within the value of 4.2 ± 0.1 by addition of a small amount of diluted sulphuric acid solution, and measured weekly during the test duration to verify that it remained within the allowable range.

Testing was performed in an Ascott 450XP salt spray test chamber, over a total duration of 4 weeks, programmed in accordance with the cyclic spraying with salt solution and variation in relative humidity between 50 % and 95 % at 35 °C. Due to equipment failure, the actual test temperature during the stages of 95 % RH was 52-53 °C. The test specimens were placed in the test rig at an inclined angle of 20 ± 5° to the horizontal as required by ISO 16701.

2.4 VDA 230-214 Corrosion Testing

Corrosion testing according to VDA 230-214 [9] was conducted at TU Dortmund, in their test rig shown in Figure 1. The corrosive synthetic condensate K2.2 was selected, consisting of a mixture of 0.035 ml/l acetic acid, 0.039 ml/l

formic acid and 1,650 mg/l NaCl dissolved in demineralised water. Thermal conditioning was performed weekly at a temperature of 400 °C. Total test duration was 6 weeks.

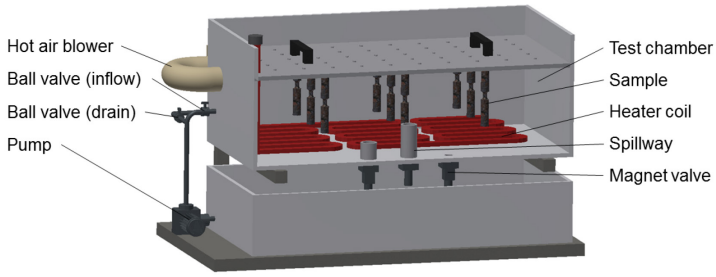


Figure 1. Schematic image of the TU Dortmund corrosion test rig (different sample design). Courtesy of Schmiedt et al. [10]

2.5 Metallographic investigation

Brazed reference specimens of each brazing filler metal - base material combination was sectioned and prepared by metallographic methods, and compared with corresponding test specimens that were subject to ISO 16701 or VDA 230-214 corrosion testing. A Leica DM6000 Light Optical Microscope was used for the investigations. The characteristics and degree of corrosion attack was evaluated qualitatively, and the different brazing filler metal – base material combinations were evaluated by corrosion resistance in each test media.

3 Results and Discussion

3.1 Brazing results

After brazing the specimens, the visual appearance of reference specimens was evaluated. The vacuum brazed samples look good in all cases, with the exception of BNi-7 where the brazing filler metal has not effectively flown along and into the joint.

There are clear differences of diffusivity of melting point depressant elements in ferritic stainless steels compared to austenitic stainless steels. Most obvious, is the distribution of boron in the case of brazing with BNi-2. In ferritic stainless steels, boride precipitation occurs both transgranularly and intergranularly, with a needle-like morphology orientated mainly perpendicular to the interface between the brazing filler metal and the base material. This is attributed to preferential diffusion passes in ferrite for boron [1] [2] [3]. Moreover, differences in diffusivity of phosphorous in ferritic stainless steels compared to austenitic stainless steels have been reported previously [1]. It was found that for short brazing times, very little P diffusion takes place in austenitic stainless steels compared to ferritic stainless steels. For P-containing brazing filler metals this implies that more P will diffuse into the base materials in a shorter time when brazing ferritic stainless steels. This will lead to faster isothermal solidification, and will reduce the amount of P-rich intermetallic compounds in the brazed joint microstructure.

Grain growth is a concern for ferritic stainless steels, both due to the fact that the negative impact on strength and ductility is more pronounced for ferritic materials compared to austenite, but also because there in most cases is no potential for grain refinement through heat treatment. Ferric stainless steels generally cannot be heat treated to be fully austenitic, and in the cases where it is possible (e.g. low Cr-content ferritic stainless steels), phase transformations occur at such a high temperature that the resulting grain size still is very large. Grain growth in ferritic stainless steels has been discussed previously in several different publications [1] [5] [6] [12]. The approach has commonly been to select low brazing temperature alloys and restrict the brazing temperature as much as possible to limit grain growth. However, in our recent work it was shown that the proper selection of brazing filler metal has a much larger impact on the overall brazed joint strength than the grain growth as result of the brazing process [16].

Grain growth was found to vary slightly between the different base materials, brazing cycles and brazing temperatures. On the low end of the scale was BNi-7 brazed in belt furnace, which is shown in Figure 2 for the case of AISI 430/BNi-7 brazed in 90 % N_2/10 % H_2 atmosphere. In this case, the brazing cycle did not lead to a complete recrystallization of the centre of the base material, and the rolling microstructure is still visible. The average grain size along the surface of this specimen was 20 µm. However, the increase when comparing to the sample with the highest brazing temperature and longest brazing time, i.e. BrazeLet F300 vacuum brazed specimens, the average grain size in the surface of the AISI 430 material showed only a slight increase to 27 µm. Another observed effect was that the AISI 430 specimens belt furnace-brazed at higher temperature than 1,050 °C, completely recrystallized, and showed excessive grain growth along the centre of the material. For brazing at 1,100 °C in belt furnace, grains

up to 200 µm were found in the centre of the base material. The same effect was not observed for vacuum brazed specimens. The reason for this has not been studied in detail.

Grain growth in the base material along the brazed joint has also been found to be dependent on the selection of the brazing filler metal. As the elements from the brazing filler metal diffuse into the base material, the chemical composition is locally changed. For example, Cr, P and Si are strong ferrite stabilisers, while Ni, Cu, C and N are strong austenite stabilisers. For the case of BrazeLet F300 tested in combination with AISI 430, it was previously found that the combined effect of Cu, Ni, Si and P is that the material within the diffusion length (50-100 µm) is more strongly ferrite stabilised than the bulk base material. If the combined effect of P and Si increases the ferrite to austenite transformation temperature higher than the brazing temperature, the result is substantial grain growth in the diffusion zone along the brazed joint, as no phase transformation can occur. In either case, if the transformation temperature is reached, the resulting grain size will still be large as transformation occurs at a higher temperature.



Figure 2. AISI 430/BNi-7 specimen brazed in 90 % N_2/10 % H_2 atmosphere. It is observed that the rolling structure still partly remains in the centre of the base material.

Due to the diffusion of elements from the brazing filler metal to the base material, there will be differences in phase transformations in the areas where the base material is in contact with the brazing filler metal, compared to the bulk base material. For the high purity Fe-Cr system, the austenite loop extends to around 13.5 wt% Cr. However, introduction of austenite stabilizing elements will extend this loop. Most potent are additions of carbon and nitrogen, but the other austenite stabilizing elements such as Ni and Cu will also have an effect. For the brazing filler metals evaluated in this work, containing significant amounts of P and/or Si the base material within the diffusion length normally is more strongly ferrite stabilised than the bulk base material, meaning that the area of the austenite loop will be reduced and the material will remain fully ferritic throughout the brazing cycle.

3.2 ISO 16701 Salt Spray Corrosion Testing

Salt spray corrosion testing showed a clear effect of the brazing atmosphere on corrosion of the base material. Significant differences between the corrosion of AISI 430 and AISI 441 was observed as can be expected. Significant staining and corrosion of the base material is observed for specimens brazed in belt furnace, and the corrosion is generally more extensive for the specimen brazed in 90 % N_2/10 % H_2 atmosphere.

It is evident that corrosion of the base material is the main issue for AISI 430 brazed joints. The corrosion attack propagates preferentially along grain boundaries, and in some locations develop pitting where the occluded environment accelerates corrosion. Corrosion is significantly more extensive in the specimens brazed in 90 % N_2/10 % H_2 or 100 % H_2 atmospheres in belt furnace. Corrosion of the brazing filler metals is rather limited in most cases. BNi-2 has the worst corrosion resistance out of the brazing filler metals tested. The brazing filler metals with high corrosion resistance, e.g. BrazeLet Ni613 and BrazeLet F300 show a tendency of preferential corrosion attack of the AISI 430 base material along the brazing filler metal – base material interface.

In AISI 441 specimens, corrosion of the base material is not significant, and no preferential corrosion attack along grain boundaries can be observed. Corrosion of the brazing filler metal is more pronounced in several of the test specimen conditions. BNi-2 and BNi-7 show significant corrosion, in both vacuum brazed and belt furnace brazed specimens. BrazeLet F300 and BrazeLet Ni613 has only minor, uniform corrosion of the brazing filler metal fillet.

When comparing the brazed joint results with the reference specimens tested in the as-delivered condition, it can be seen that particularly for AISI 430, the corrosion of the base material is much more extensive after subjected to the brazing cycle.

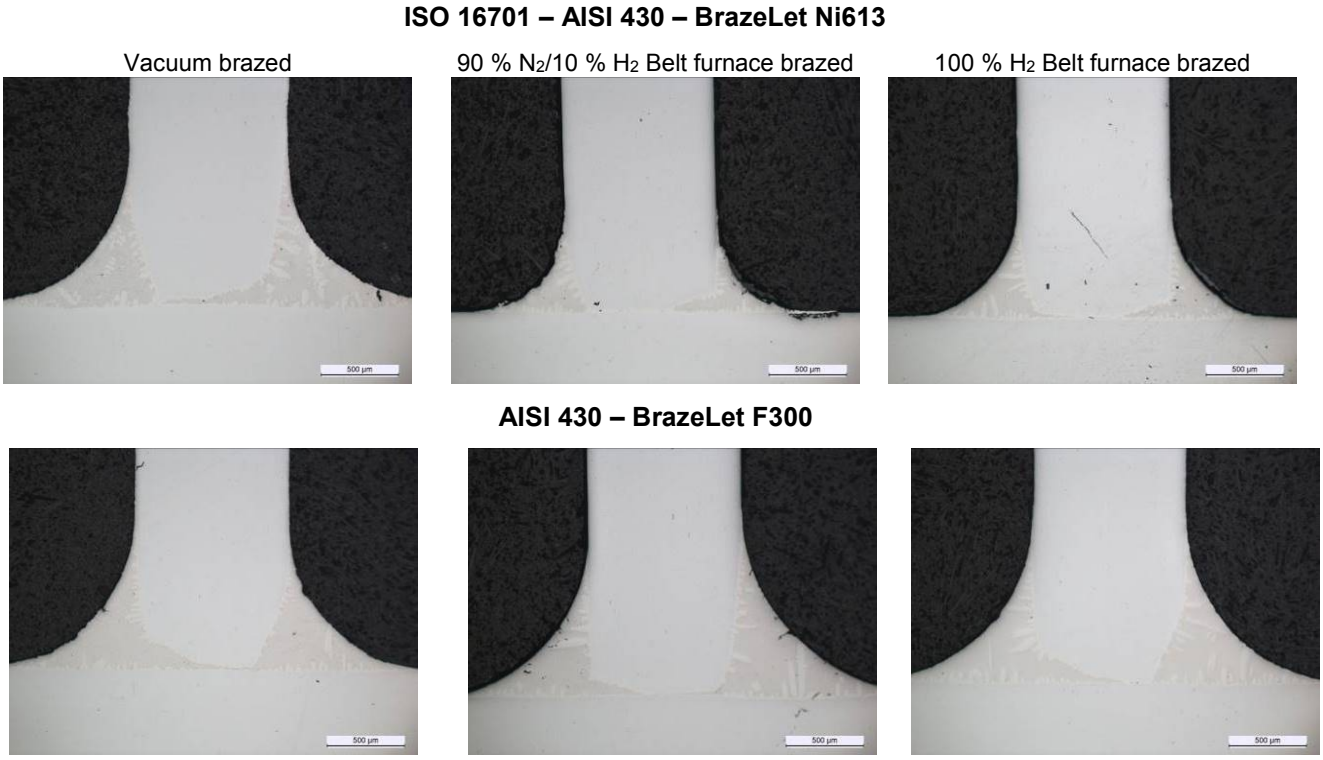


Figure 3. Examples of brazed joint microstructures after being subjected to 4 weeks ISO 16701 salt spray corrosion testing.

3.3 VDA 230-214 Corrosion Testing

VDA 230-214 corrosion testing showed the same effect of the brazing cycle and brazing atmosphere as the ISO 16701 salt spray corrosion testing, but the corrosion was more extensive. Significant localized corrosion attacks are observed in the AISI 430 base material. Severe base material corrosion is observed for AISI 430 in all three brazing atmospheres, but is most extensive for the belt furnace brazed specimens. Corrosion propagates preferentially along grain boundaries. In some locations, the initial corrosion attack on the surface develops further to extensive pitting corrosion into the base material. In contrast, no significant base material corrosion is observed for the AISI 441 specimens.

For the AISI 430/BNi-2 vacuum brazed specimen corrosion propagates along the interface line between the base material and the brazing filler metal, where Cr-borides have precipitated and led to a Cr-depleted zone with lower corrosion resistance than the bulk base material. The same effect was seen for the specimen brazed in 100 % H_2 atmosphere in belt furnace, but much less extensive. Here, corrosion progresses mainly by corrosion of certain phases in the brazing fillet. There is a notable difference in Cr-boride precipitation between the two samples, with more extensive and coarser boride precipitation in the vacuum brazed specimen. For the AISI 441/BNi-2 vacuum brazed specimen, corrosion along the interface line is not observed and corrosion occurs by preferential attack of certain phases in the brazing fillet.

For AISI 430/BNi-7 and AISI 441/BNi-7 specimens, poor flow of the brazing filler metal along and into the joint is observed for most specimens. Corrosion occurs as uniform corrosion across the brazing fillet. Corrosion of the brazing filler metal is more extensive for the AISI 441/BNi-7 specimens compared to AISI 430/BNi-7. No effect of the brazing atmosphere on the corrosion resistance can be observed for BNi-7.

For AISI 430/Ni613, severe corrosion in the AISI 430 base material which initiates along the brazing filler metal – base material interface is observed for most specimens. The vacuum brazed and 100 % H_2 belt furnace-brazed specimens show no significant corrosion of the brazing filler metal, while the specimens brazed in 90 % N_2/10 % H_2 atmosphere show signs of corrosion in the brazing filler metal. For the AISI 441/Ni613 specimens, some corrosion of the brazing filler metal is observed. More extensive corrosion is observed for the specimens brazed in 90 % N_2/10 % H_2 atmosphere, compared with the ones brazed in vacuum.

For AISI 430/F300 brazed specimens, no significant corrosion of the brazing filler metal is observed. In these specimens, severe corrosion of the AISI 430 base material is observed. The corrosion typically initiates at the interface

between the brazing filler metal and the base material and progresses either along the interface line or into the base material as pitting corrosion. No effect of the brazing atmosphere can be observed on the brazing filler metal corrosion resistance, but the base material is significantly affected as discussed above. For AISI 441/F300 brazed specimens, only minor uniform corrosion of the brazing filler metal can be observed.

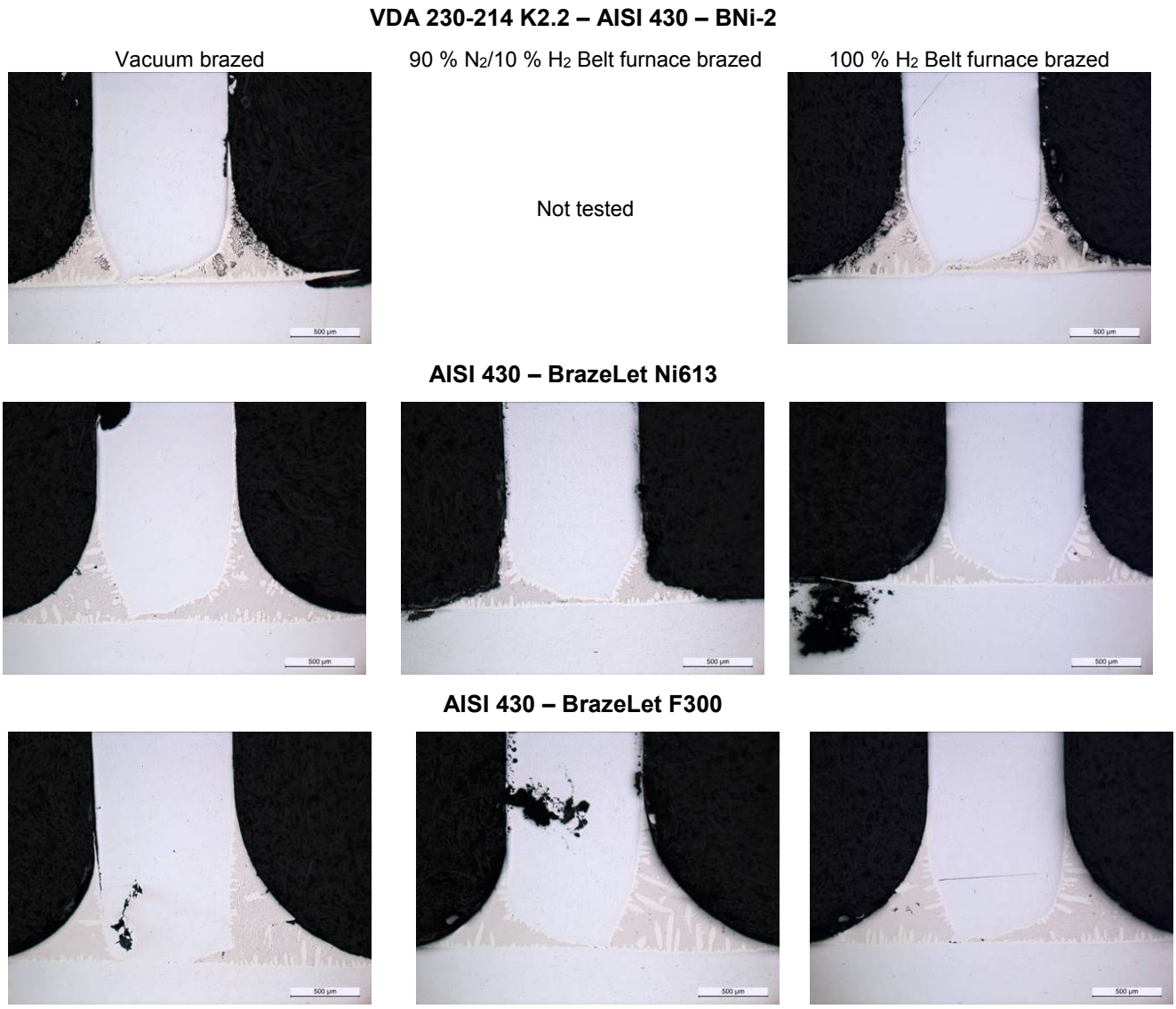


Figure 4. Examples of brazed joint microstructures after being subjected to 6 weeks VDA 230-214 K2.2 corrosion testing.

3.4 Base material corrosion resistance and effect of brazing cycle and atmosphere

From both the ISO 16701 salt spray corrosion test results and the VDA 230-214 synthetic condensate corrosion test results it is clear that the brazing cycle and the brazing atmosphere can affect the corrosion resistance of the base materials involved. In particular, the effect on the un-stabilised grade AISI 430 is significant, while the effect for the Ti+Nb dual stabilised grade AISI 441 is less pronounced. Prior to the brazing cycle (in the as-delivered condition), no difference in corrosion resistance can be observed between AISI 430 and AISI 441 in the tests performed. After the specimens were subject to the brazing cycle, the corrosion resistance of AISI 430 is significantly lower in all cases, but most pronounced for the belt furnace brazed specimens. Preferential corrosion along the grain boundaries is observed for belt furnace-brazed AISI 430, which suggests sensitisation of the base material as a result of the brazing profile.

The clear difference between the vacuum brazed and belt furnace brazed AISI 430 specimens suggests that the belt furnace brazing profile in this case increased sensitisation of the base material. Sensitisation of stainless steels can be defined as susceptibility to intergranular corrosion, which occurs due to chromium-depleted zones at the grain boundaries associated with precipitation of chromium carbides. Sensitisation occurs in the temperature area between 500 – 900 °C, at temperatures higher than 950 °C, the Cr-carbides are dissolved and concentration differences are over time eliminated by diffusion. If carbon is present in the material, as is the case for AISI 430, Cr-carbides will precipitate upon cooling below approximately 900 °C. Depending on the cooling rate through this range, there will be

differences in the local Cr-concentrations along the grain boundaries. With more rapid cooling, less time for diffusion is available and larger differences can be expected. This could explain why the corrosion resistance along the grain boundaries in the belt furnace brazed specimens is lower compared to the vacuum brazed specimens where the cooling rate is significantly lower.

One difference between the austenitic stainless steels previously studied and the ferritic stainless steels investigated in this work is the effect on nitrogen on the phase stability of the base material surface. As previously discussed, nitrogen is a potent austenite stabiliser and will lead to austenite being the equilibrium phase at elevated temperatures during the brazing cycle. Even small concentrations of nitrogen will significantly increase the stable area of austenite. Fedorov et al. reported base material concentrations up to 0.50 wt% N in the AISI 304 base material surface after brazing at 1,150 °C [7]. The N concentration in the surface for the case of the ferritic stainless examined here has not been quantified, but a clear effect along the surface of the samples brazed in 90 % N_2/10 % H_2 atmosphere is observed. The effect is more pronounced with increasing temperature, which corresponds to increased nitrogen content in the base material surface, and is observed in both AISI 430 and AISI 441.

3.5 Brazed joint corrosion resistance and effect of brazing cycle and atmosphere

Although the base material is found to be clearly affected by the brazing cycle and the process atmosphere, it is more relevant to look at the effect on corrosion resistance of the brazed joint as a whole. From the results, it is clear that only minor differences on the brazing filler metal corrosion resistance result from different brazing atmospheres. Actually, BrazeLet Ni613 is the only brazing filler metal where a significant impact of the brazing atmosphere can be seen, with more extensive corrosion of the brazing filler metal in the test specimen brazed in 90 % N_2/10 % H_2 atmosphere. It is suggested that the reason for the clear effect on BrazeLet Ni613, compared to other alloys is related to the higher Cr-content with 29 wt% compared to 20 wt% for BrazeLet F300, leading to increased formation of Cr-nitrides. Due to their moderate thermodynamic stability, formation of Cr-nitrides are limited to atmospheres with very high nitrogen activities or alloys with Cr-contents above ~20 wt%. Hence, formation of Cr-nitrides are expected to be more extensive in BrazeLet Ni613 compared to the other brazing filler metals tested in this work.

For BNi-2 a clear effect of the brazing cycle on how the corrosion propagates is observed. For vacuum brazed specimens, corrosion propagates along the brazing filler metal – base material interface line in the diffusion zone where Cr-borides have precipitated. For the belt furnace brazed specimens, the precipitation of Cr-borides was observed to be less extensive, which could explain the fact that corrosion in these specimens progress by attack of certain phases in the brazing fillet, rather than preferential corrosion along the interface line.

The difference in corrosion potential between the brazing filler metal, the diffusion zone and the base material will impact how the corrosion initiates and propagates. Iwata et al. measured differences in corrosion potential of the brazing filler metal and the base material, and this potential difference can promote localized galvanic corrosion [5]. The effect is limited to the interface area between the two materials, due to the IR drop in the electrolyte which increases with distance. The observed tendency for initiation of corrosion along the interface between the brazing filler metal and the base material is attributed to this galvanic coupling effect of the two materials with different corrosion potentials. For the more corrosion resistant brazing filler metal used, there is a larger tendency of corrosion attacks along this interface. Corrosion initiates along this line and proceeds further by pitting corrosion into the base material where the occluded aggressive environment further increases the corrosion rates. Several examples of this effect are seen in Figure 4.

4 Conclusions

In this work, the influence of brazing atmosphere on brazed joint corrosion resistance was studied for ferritic stainless steel grades AISI 430 and AISI 441 and Ni- and Fe-base brazing filler metals. Corrosion resistance was tested by ISO 16701 cyclic salt spray corrosion testing and VDA 230-214 synthetic exhaust condensate corrosion testing to simulate conditions relevant for the external, as well as the internal joints, in brazed components. The following conclusions could be made:

- It is feasible to braze AISI 430 and AISI 441 with all tested brazing filler metals in vacuum, 90 % N_2/10 % H_2 and 100 % H_2 atmospheres. However, BNi-7 has particularly poor wetting characteristics on ferritic stainless steels and issues related to incomplete gap filling was observed.
- ISO 16701 salt spray corrosion testing results in rather limited corrosion of the brazing filler metals for most specimens. BNi-2 was found to be most susceptible to corrosion, but scattered corrosion attacks was also observed in F300 specimens.
- In general, corrosion of AISI 430 and AISI 441 base material is more extensive in specimens brazed in belt furnace, compared to vacuum furnace. The specimens brazed in 90 % N_2/10 % H_2 atmosphere corrode more than the ones brazed in 100 % H_2 atmospheres.
- AISI 430 specimens brazed in the belt furnace showed clear signs of sensitisation of the base material, with preferential corrosion along the grain boundaries of the material. The same effect was not observed in the

vacuum brazed specimens subject to slower cooling rates after brazing. As expected, the Ti+Nb dual-stabilised AISI 441 did not show signs of sensitisation.

- Brazing in 90 % N_2/10 % H_2 atmosphere resulted in a nitrogen enrichment of the surface layer in both AISI 430 and AISI 441. As N is a potent austenite stabilising element, this enrichment led to changes in the base material surface microstructure.
- BrazeLet Ni613 was the only brazing filler metal where the corrosion resistance depended on the brazing atmosphere. Specimens brazed in nitrogen-containing atmospheres resulted in increased corrosion of the brazing filler metal. This is attributed to formation of Cr-nitrides in Ni613 due to the high Cr-content compared to other brazing filler metals tested.

5 Acknowledgements

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