Iron-based Brazing Filler Metals for High Temperature Brazing of Stainless Steel

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This paper presents newly developed brazing filler metals for high temperature brazing of stainless steels.

The development of the new alloys has been driven by the market demand to find low cost alternatives to Ni based brazing filler metals used in high end applications like heat exchangers and EGR coolers. High and fluctuating raw material costs for the Ni alloys resulted in that the new brazing filler metals are based on iron.

The iron based brazing filler metals have been evaluated in several brazing trials. The evaluation included wetting and spreading investigations, metallographic examinations, joint strength and corrosion resistance. Results from the evaluation have been benchmarked against commercial available brazing filler metal and are presented in this paper. The conclusion is that the newly developed iron based brazing filler metals fulfil the requested properties for high end applications.

1 Introduction

The demand on the filler metals used in high end applications has over the past years become tougher due to new environmental legislations. Nickel based brazing filler metals have been the first choice for demanding applications. HBNi613 was developed specially for the new generation of EGR coolers which operates at high service temperatures and in corrosive environments. HBNi613 brazes at a low temperature (1080°C), has high strength and good corrosion resistance [1]. BNi5 has good corrosion resistance but brazes at rather high temperature (1150°C). BNi2 brazes at lower temperature (1050°C), has good strength but the corrosion resistance is low. The fluctuating raw material cost has driven the need to explore low cost alternatives to the nickel based alloys.

This paper presents the development of two new iron based brazing filler metals. F302 was benchmarked against BNi2 and F300 was benchmarked against BNi5 and HBNi613.

2 Experimental Procedures

2.1 Brazing filler metals

The nominal compositions and braze temperature of the brazing filler metals used in the investigation are found in **Table 1**.

F302 and F300 are iron based alloys. F302 contains 15wt%Cr, 10wt%Ni, 5wt%Cu, 5wt%Si, 9wt%P and the balance being Fe. F300 contains 27wt%Cr, 20wt%Ni, 10wt%Cu, 5wt%Mn, 5wt%Si, 7wt%P and the balance being Fe. F302 was developed to be a low cost alternative to BNi2 whereas F300 was benchmarked against high performance Ni-based alloys like BNi5 and HBNi613 [2]. F302 and F300 are boron free.

As references three nickel based alloys and two iron based alloys were used. BNi2, BNi5 and HBNi613 are Ni-based filler metals and Fe-1150 and Fe-1190 are iron based alloys found in the literature [3, 4].

Comp wt%	F302	F300	BNi2	BNi5	Ni 613	Fe-1150	Fe-1190
Cr	15	24	7	19	29	29	18
Ni	10	20	Bal	Bal	Bal	15	13
Fe	Bal	Bal	3	-	-	Bal	Bal
Si	5	5	4	10	4	3	11
P	9	7	-	-	6	7	-
B	-	-	3	-	-	-	1
Mn	-	5	-	-	-	-	2
Cu	5	10	-	-	-	-	-
Mo	-	-	-	-	-	-	2
Braze temp °C	1100	1100	1050	1150	1080	1150	1190

Table 1. Nominal composition and braze temperature of used brazing filler metals

2.2 Brazing profile

The brazing was conducted in a batch vacuum furnace at the optimal braze temperatures found in Table 1. The braze time was 30min and the vacuum was 10^{-4} torr.

2.3 Performed tests

2.3.1 Wetting test

Wetting is an important property as the melted alloy in some cases must flow into wide and long gaps. To evaluate the wetting of the brazing filler metals 316L stainless steel substrates were used as base material. The substrates were 50x50mm. About 0.2g of powder was placed at the centre of the substrates in the shape of a circle with 9mm diameter. This will give an initial powder area (A_i) of 63,6mm^2 ($\pi * r^2$).

The substrates were heated in vacuum under the conditions mentioned above to cause the melting and spreading of the filler metal on the base substrate. The wetting was determined in terms of the spreading ratio S defined as

$$S = A_m/A_i \qquad\qquad (1)$$

where A_i is the area of the initial filler metal and A_m the area covered by the melted filler metal.

2.3.2 Metallographic examination

The microstructure of the joint is important as it determines the strength of the brazed joints. A continuous brittle phase should be avoided. Elements, like boron should be avoided if possible as it might form brittle borides within the brazed joint. F300 and F302 do therefore not contain any boron.

T-specimens were brazed with approximately 0.2g of paste. The brazed T-specimens were cross sectioned and the microstructure was analyzed in the Light Optic Microscope (LOM). Micro hardness was measured with Buehler Omnimet MHT with 100g load ($HV_{0,1}$)

2.3.3 Joint strength

The joint strength was measured using similar procedures to those described in AWS standard C3.2M/C3.2:2001 [5]. Lap-sheer specimens according to **Figure 1** were used. It was decided not to do any mechanical post-treatments on the specimens after brazing. Both 0 and 100µm gap specimens were used. To obtain a gap of 100µm a stainless steel thread was placed between the parts to create the specific gap width. The base material was stainless steel 316L. About 0.4g of paste was placed on the specimens before brazing. The specimens were heated under the conditions mentioned above.
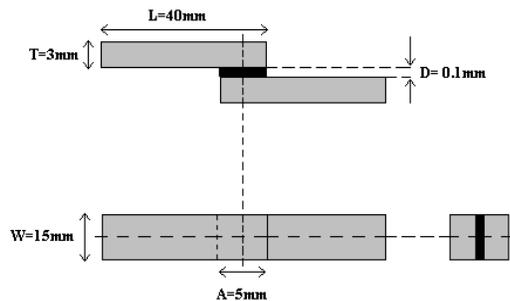

Figure 1. Joint strength bars according to AWS C3.2M/C3.2:2001

2.3.4 Corrosion test

Corrosion tests were conducted by placing tablets of the melted filler metals in beakers with 10% H_2SO_4 solutions in room temperature. The weight of the tablets were measured before placed in the beakers and after 24h, 48h and 72h respectively. The weight loss was calculated.

A second corrosion test was conducted by placing brazed samples in the beakers with 10% H_2SO_4

solution in room temperature. The microstructures of the brazed samples were investigated after one week to see if they had been affected by the solution or not.

3 Results and discussions

3.1 Wetting and spreading ratio

The spreading ration for F302 is 2,2% and for F300 8,8% – see **Figure 2**. This means that F302 has better wetting on stainless steel than BNi2 (1,1%). F300 on the other hand has very good wetting but less than Ni613 (11,6%). Fe-1150 has also rather good wetting while Fe-1190 has wetting comparable to F302.
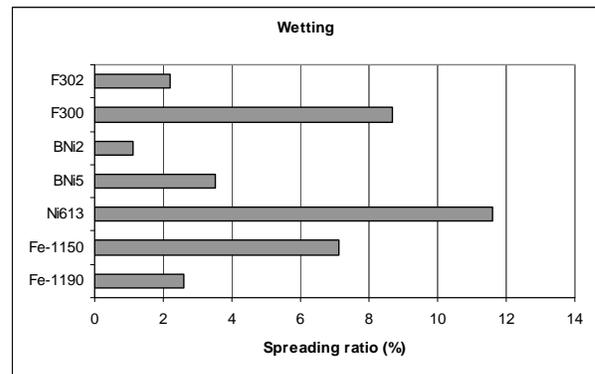

Figure 2. Spreading ratio comparison of the different alloys.

3.2 Metallographic examination

The microstructure in F302 and F300 consists of a homogenous mix of a hard FeCrNiP-rich phase surrounded by a ductile FeCrNi-rich phase, **Figure 3**.The ductile phase prevents cracks from spreading. No continuous brittle phase is found in the microstructure even at wider gaps.
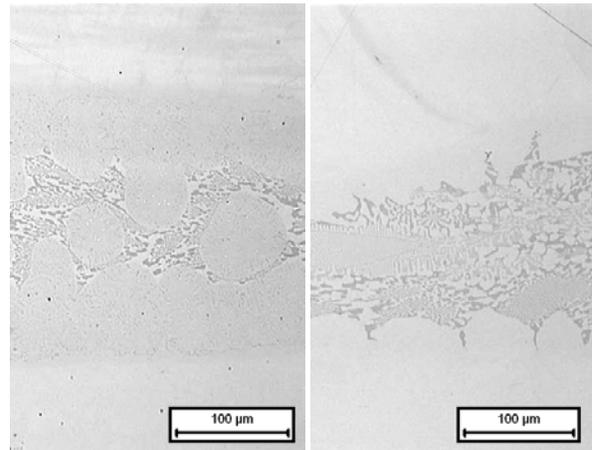

Figure 3. Microstructure of brazed joint F302 (left) and F300 (right)

The joint micro hardness is found in **Figure 4**. The mean joint micro hardness of F302 is 420HV$_{0,1}$ which is much less than BNi2. F300 has a micro hardness of 510HV$_{0,1}$ which is slightly higher than Ni613. F302, F300, Ni613 and Fe-1150 are all in the same micro hardness range. These alloys do not contain B and hence no brittle phases are found in the microstructure. BNi2, BNi5 and Fe-1190 contain high Si and/or B which forms harder joints.
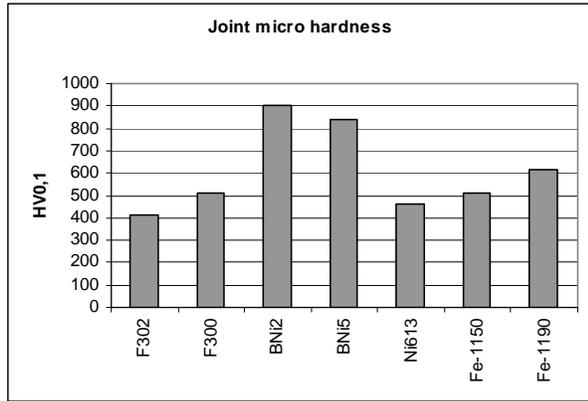
Joint micro hardness

Figure 4. Micro hardness

A micro hardness profile was done through the brazed joint of F302 – see **Figure 5**. The profile was measured at 300µm gap as well as 150µm gap. As seen the micro hardness is constant through out the joint with no peaks exceeding 550HV$_{0,1}$ even at wider gaps. This indicates that no hard phases start to form at wider gaps. The same behaviour was seen in F300.
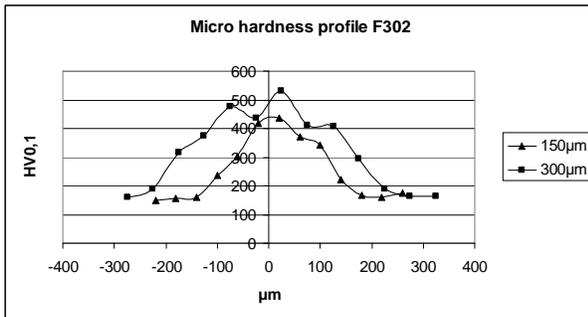
Micro hardness profile F302

Figure 5. Micro hardness profile in joint

Wide gap tolerance can be an important property to ensure good brazed joints without cracks. Tests were done with all alloys and F302 and BNi2 is used as examples - **Figure 6**. F302 does not form a continuous brittle phase at wider gaps. BNi2 starts to form a continuous brittle phase at about 70µm and at 120µm a crack has formed.
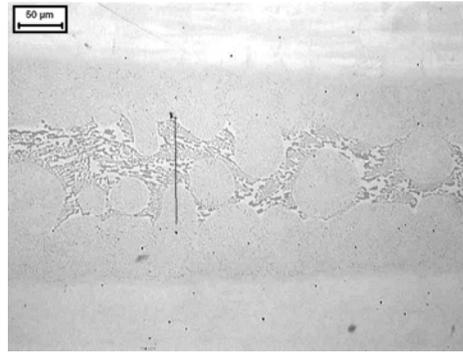
a) F302 @ 120µm
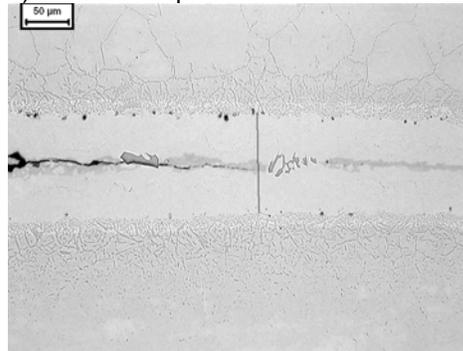
b) BNi2 @ 120µm

Figure 6. Wide gap test specimens comparing F302 with BNi2 at 120µm gap width.

3.3 Joint strength

The joint strength with both 0µm and 100µm gap specimens are found in **Figure 7**.

The strength of F302 is very similar to the strength obtained with BNi2. F300 has higher strength than BNi5 but lower than Ni613. Fe-1150 is in the same range as Ni613 while Fe-1190 is much higher. As expected the strength for the 0µm gap specimens are higher than the 100µm gap specimens.
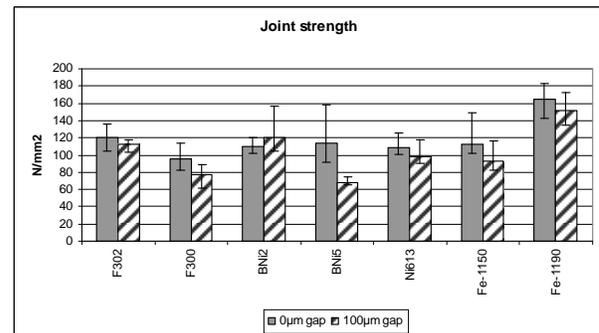
Joint strength

**Figure 7.** Joint strength comparison at 0µm and 100µm gap.

3.4   Corrosion tests

The results from the corrosion tests are found in **Table 2**. As seen from the table F302 has better corrosion resistance in 10% H_2SO_4 solution than BNi2. F302 does not corrode at once. The weight loss started after 48h and was not very aggressive. F300 has corrosion resistance similar to BNi5 and HBNi613 and does not corrode in 10% H_2SO_4 solution. Fe-1190 has also good corrosion resistance while Fe-1150 starts to corrode after 48h. Once the corrosion starts it is rather aggressively.

Alloy	Weight loss in 10wt% H_2SO_4		
	24h	48h	72h
F302	0	-3	-4
F300	0	0	0
BNi2	-2	-9	-16
BNi5	-1	-2	-3
Ni613	0	0	0
Fe-1150	0	-11	-28
Fe-1190	0	0	0

Table 2. Weight loss of the alloys in 10wt% H_2SO_4

Micrographs of brazed joints of F302 and BNi2 after one week in 10wt% H_2SO_4 solution are found in **Figure 8**. It is clearly seen that BNi2 is highly corroded at the surface as well at the borderline between the brazed joint and base material. The joint with F302 is not affected at all.
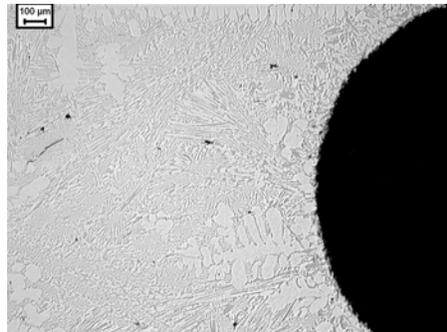
a) F302
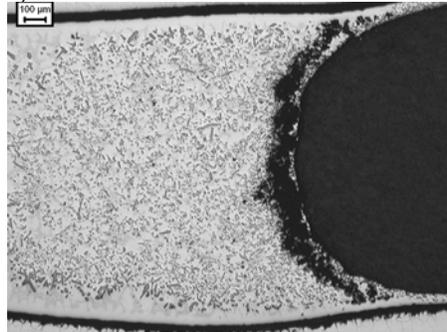
b) BNi2

Figure 8. Micrographs of the brazed joints after 1week in 10% H_2SO_4

4.   Conclusion

The investigations show that the newly developed iron based brazing filler metals are a good low cost alternative to Ni-based brazing filler metals. F302 and F300 have unique compositions developed for brazing stainless steel applications in high end applications. Further more; both F302 and F300 require a moderate brazing temperature.

F302 has very good strength and better corrosion resistance than BNi2.

F300 has very good wetting on stainless steel and the braze temperature is lower than for BNi5. The strength of F300 is higher than BNi5. The corrosion resistance is comparable to HBNi613 in H_2SO_4.

Compared to the Fe-based filler metals used as references both F302 and F300 has lower braze temperature. F300 also has better wetting and spreading then the reference Fe-based alloys.

The microstructure in F302 and F300 is similar to the one found in Fe-1150. Fe-1190 on the other hand has a lot of needle shaped hard phases. The joint strength of F302 in lap-shear test is considerably higher than Fe-1150 but lower than Fe-1190. The joint strength for F300 is slightly lower than for Fe-1150. The lower brazing temperature and better wetting on steel substrates is however a strong advantage for F300 over Fe-1150 and Fe-1190.

Note: The compositions of F302 and F300 are covered by pending patents of Höganäs AB.

5.   References

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[5]   American Welding Society: Standard method for evaluating the strength of brazed joints, AWS C3.2M/C3.2:2001