New iron-chromium based brazing filler metal for demanding stainless steel applications

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Nickel based brazing filler metals are commonly used in applications with high demands. Due to fluctuating raw material costs the performance of a low cost alternative to the Nickel based alloys was investigated.

This paper presents an iron-chromium based brazing filler metal appropriate for brazing stainless steel. The alloy is suitable for brazing heat exchangers and EGR coolers with tough requirements on strength and corrosion resistance.

The new brazing filler metal was tested in several brazing trials. The brazed joints were investigated by metallographic examinations, joint strength and corrosion resistance. The target was to benchmark against commercial available brazing filler metals.

The investigations show that the alloy has excellent wetting and brazing on 316L stainless steel. The microstructure consists of a homogenous mixed matrix. The brazed joint has high strength and good corrosion resistance. The brazing temperature for the alloy is lower than for BNi5.

1. Introduction

The demand on the filler metals used in high corrosive environments has over the past years become tougher due to new gas emission regulations. Nickel based brazing filler metals have been the first choice for these 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^{o}C), has high strength and good corrosion resistance [1]. BNi5 has good corrosion resistance but brazes at rather high temperature 1150^{o}C. BNi2 brazes at lower temperature 1100^{o}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 investigation of a new FeCr-based gas atomized filler metal designed to match the properties of BNi5. The FeCr-based brazing filler metal has been benchmarked against several commercial available brazing filler metals.

2. Experimental Procedure

Brazing filler metals

Table 1 shows the nominal composition and the braze temperature of the brazing filler metals used in this investigation. The FeCr brazing filler metal contains 27%Cr, 20%Ni, 10%Cu, 5%Si, 7%P, 5%Mn and the balance being Fe. The high Cr content and also the presence of Cu are intended for improving corrosion resistance. Ni is present to gain high strength and Si, P and Mn are acting as melting point depressants to keep the melting temperature in a workable range.

Three nickel based brazing filler metals and two iron based filler metals as described in literature [2,3] were used as references.

Table 1 Nominal composition and braze temperature of the braze filler metals

Comp. weight%	FeCr	BNi2	BNi5	613	Fe-1150	Fe-1190
Cr	27	7	19	29	29	18
Ni	20	Bal	Bal	Bal	15	13
Fe	Bal	3	-	-	Bal	Bal
Si	5	4	10	4	6	11
P	7	-	-	6	7	-
B	-	3	-	-	-	1
Mn	5	-	-	-	-	2
Cu	10	-	-	-	-	-
Mo	-	-	-	-	-	2
Braze temp ^{o}C / ^{o}F	1100/ 2012	1100/ 2012	1150/ 2100	1080/ 1976	1150/ 2100	1190/ 2174

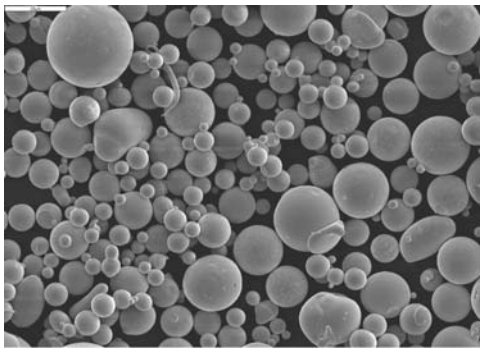


Figure 1 Gas atomized FeCr

Brazing procedure

The brazing was conducted in a batch vacuum furnace. The optimal braze temperature for each brazing filler metal was used - see Table 1. The hold time at braze temperature was 1h. The vacuum was about $5*10^{-5}$ Torr at braze temperature.

Performed tests

Wetting

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 and 0.2g of powder was placed at the centre of the substrates. 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

$S=A_f/A_s$ (1)

where A_f is the area covered by the melted filler metal and A_s the substrate area.

Metallographic examination

The microstructure of the joint is important as it determines the strength. 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. FeCr does 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.

Joint strength

The joint strength was measured using similar procedures to those described in AWS standard C3.2M/C3.2:2001 [4]. Lap-sheer specimens according to Figure 2 were used. It was decided not to do any mechanical post-treatments on the specimens after brazing. A stainless steel thread was placed between the parts to create a specific gap width (100µm). The base material was stainless steel 316L. 0.6g of paste was placed on the specimens before brazing.

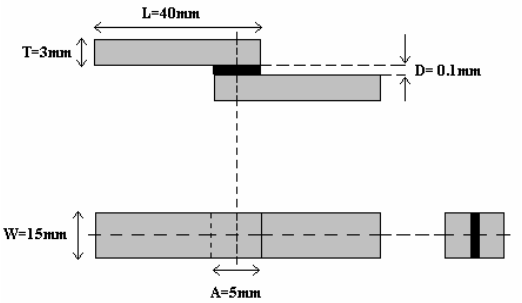


Figure 2 Joint strength bars according to AWS C3.2M/C3.2:2001

Corrosion tests

Corrosion tests were conducted at Swerea KIMAB in Stockholm, an institute specialized in material characteristics and corrosion resistance. Duplicates of brazed T-specimens brazed with FeCr, BNi2, BNi5, HBNi613 and Fe-1150 were tested in HCl, H_2SO_4 and HNO_3 solutions in room temperature. The samples were placed in the corrosion solutions for four weeks. After four weeks the samples were cross-sectioned and inspected thoroughly.

In addition joint strength bars brazed with FeCr, BNi2, BNi5 and HBNi613 were tested in H_2SO_4 for four weeks. The bars were then tested for joint strength.

3. Results and discussions

Wetting

Figure 3 summarizes the results from the wetting test on 316L stainless steel substrate. The spreading ratio for FeCr, as defined in (1) exceeds those for BNi2, BNi5, Fe-1190 and Fe-1150. HBNi613 has very

good wetting with about 60% spreading ratio. This shows that the alloys containing P has very good wetting. It also shows that Cu has a positive effect on the wetting; FeCr has better wetting than Fe-1150 which does not contain Cu.

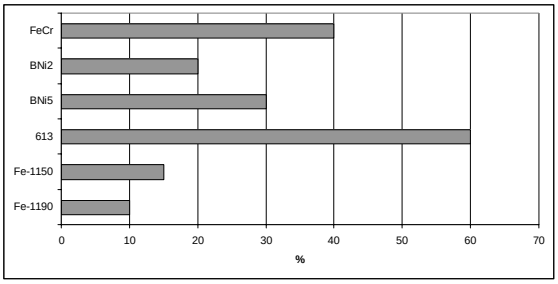
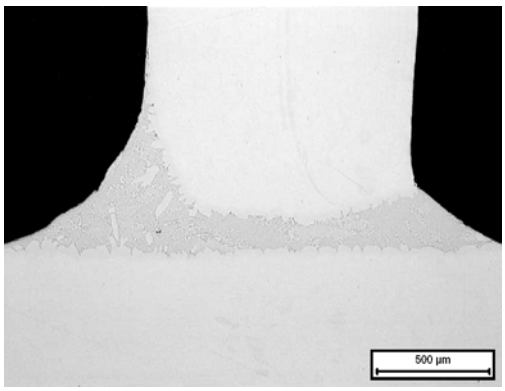


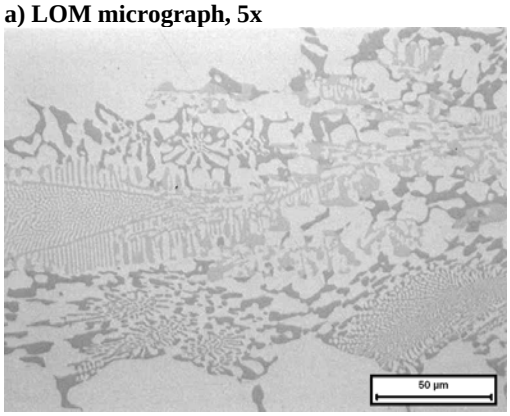
Figure 3 Wetting on 316L stainless steel substrate

Metallography

The microstructure in the FeCr brazed joint contains a homogenous mix of a hard FeCrNiP-rich phase surrounded by a ductile FeCrNi-rich phase, Figure 4. If there is a crack in the hard phase it will stop in the surrounding ductile phase. A good mix of the two phases is therefore important. No continuous brittle phase is found in the joint.



a) LOM micrograph, 5x



b) LOM micrograph, 50x

Figure 4 Microstructure of the FeCr brazed joint on a T-specimen

The micro hardness of the FeCr joint is 510$HV_{0,1}$ which is comparable to the micro hardness of Fe-1150 and slightly higher than HBNi613 joint – see Figure 5. These alloys do not contain B hence no brittle borides are formed. Figure 6 shows the micro hardness profile through the FeCr brazed joint of two different gap sizes, 150µm and 300µm gap. The diagram shows that there are no extremely hard phases within the microstructure.

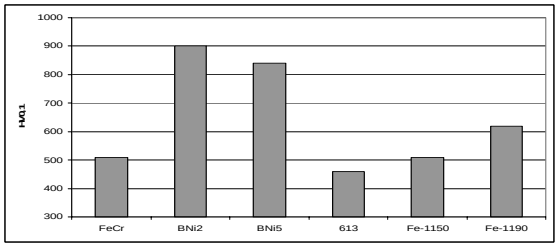


Figure 5 Joint micro hardness HV0.1 (100g load)

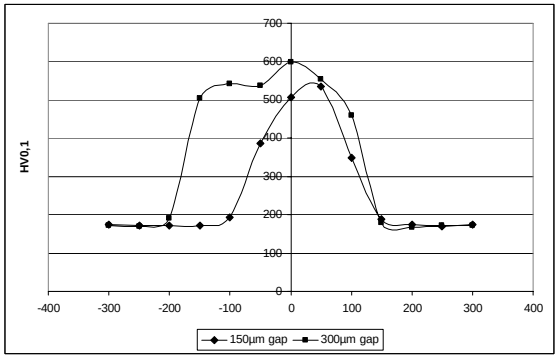


Figure 6 Micro hardness profile through the FeCr brazed joint

Joint strength

The joint strength , as seen in Figure 7 is 80N/mm^2 for FeCr. This is comparable to BNi5 and slightly below the values for BNi2, HBNi613 and Fe-1150.

By using lap-sheer testing method the effect of the fillets of the brazed joints is also included. A large joint fillet will result in higher values. A filler metal with good wetting will form smaller fillets than a filler metal with poor wetting. This means that the strength of poor flowing filler metals like Fe-1190 and Fe-1150 are enhanced while the

strength of good flowing filler metals like 613 and FeCr is reduced when using this method.

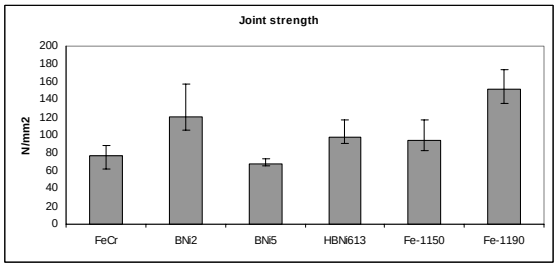


Figure 7 Joint strength

Corrosion resistance

The corrosion tests shows that FeCr has corrosion resistance comparable to HBNi613 in H_2SO_4 solution and slightly less corrosion resistance than HBNi613 in HCl and HNO_3, see Figure 8. Here it can be seen that Cu has a positive effect on the corrosion; FeCr has better corrosion resistance than Fe-1150 which does not contain Cu.

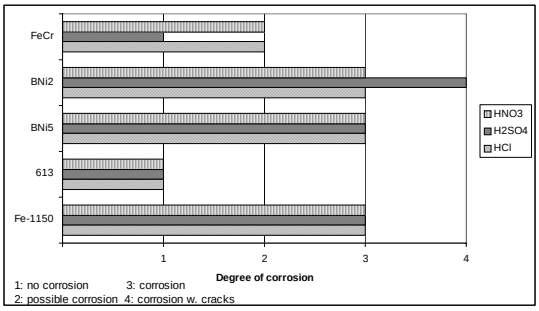


Figure 8 Results from the corrosion tests

As seen from the diagrams in Figure 9 the only material which is affected by the four weeks in H_2SO_4 solution is BNi2. The strength of this material is reduced significantly. This correlates well with the chemical composition of the alloy; BNi2 has low Cr content.

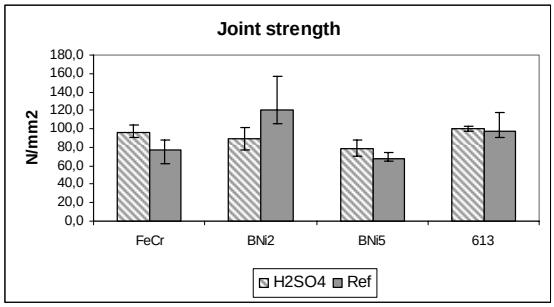


Figure 9 Joint strength after four weeks in H_2SO_4

4. Conclusions

The investigations show that the newly developed FeCr based brazing filler metal is a good low cost alternative to Ni-based brazing filler metals. FeCr has a unique composition developed for brazing stainless steel applications in high corrosive environments. Further more; FeCr requires a moderate brazing temperature.

FeCr has very good wetting on stainless steel substrates. The brazing temperature for FeCr is lower than for BNi5. The strength of FeCr 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 FeCr has better wetting and spreading and the brazing temperature is lower. The microstructure of FeCr 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 FeCr in the lap-shear test is slightly lower than for Fe-1150 and significantly lower than Fe-1190. The lower brazing temperature and better wetting on steel substrates is however a strong advantage for FeCr.

Note: The composition of the FeCr alloy is covered by a pending patent of Höganäs AB.

6. References

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