Development of Novel Fe-Cr Based Brazing Filler Metals

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Abstract

High volume users of nickel based brazing material have been dramatic increase in their brazing costs due to soaring nickel prices. In response to these changing market conditions, novel Fe-Cr based brazing filler metals were developed which performs high strength, high corrosion resistance and with low cost alternative to traditional nickel based brazing filler metals. Several types of Fe-Cr-Ni-Mo-Si-P system filler metals are developed.

Sound brazing joints were obtained with those filler metals. Very fine microstructure was observed at the brazed layer and the fillet. Almost the same joint strength as traditional Ni brazing filler metal was obtained by shear strength test. Sufficient corrosion resistance was shown by the results of both dipping and salt splay corrosion tests.

Introduction

In common recognition about the global warming, vehicle's exhaust emission gas is understood one of the main factors of the problem being caused environmental pollution. In Japan, emission gas from the diesel car such as particle matter (PM), NOx and SOx became a big problem and now the diesel cars have to equip emission gas reduction device. Even more, emission gas regulation is getting stringent year by year. So Exhaust Gas Recirculation (EGR) cooling system is understood the most effective solution to decrease the emission gas from diesel engine and its demand has been rapidly extended.

For manufacturing EGR cooler, Ni based brazing filler metals have been used to meet system requirements such as high temperature resistance and corrosion resistance. However, high volume users of Ni based brazing materials have seen dramatic increase in their brazing costs due to soaring nickel prices. In response to these changing market conditions, a new high strength, low cost alternative to traditional nickel brazing materials needed to be developed

We developed Fe-Cr based filler metals which show very similar performance characteristics to nickel filler metals; including brazing temperature, mechanical properties, corrosion resistance and heat resistance. We investigated the basic characteristics of those brazing filler metals to know further information about brazing performances.

Experimental Procedure

Table 1 shows newly developed Fe-Cr based filler metals. Solidus and liquidus temperatures were measured by differential thermal analysis (DTA) analysis. Each filler metals were contained less than 30% of Ni and Fe + Cr were balanced. Cr contain was kept more than 20% to improve corrosion resistance. Ni and Mo were added to obtain finer grain structure in order to obtain higher strength and improved corrosion resistance of the filler metals. P and Si were added to decrease melting point to have same level as traditional Ni brazing filler metals.

Table 1 Chemical compositions and melting point of newly developed Fe-Cr based filler metals.

Type	Chemical Compositions (wt%)						Solidus	Liquidus	Brazing Temp.
	Fe	Cr	Ni	Mo	Si	P	°C	°C	°C
IronBraze TB-3025	30	25	30	2	6	7	1,010	1,065	1,100 – 1,120
IronBraze TB-3520	35	20	30	2	5	8	1,010	1,060	1,100 – 1,120
IronBraze TB-4025	40	25	20	2	6	7	1,030	1,085	1,120 – 1,140
IronBraze TB-4520	45	20	20	2	5	8	1,020	1,080	1,100 – 1,130
IronBraze TB-5020	50	20	15	2	5	8	1,035	1,100	1,130 – 1,150
IronBraze TB-5520	55	20	10	2	5	8	1,060	1,115	1,150 – 1,180
IronBraze TB-6020	60	20	5	2	5	8	1,090	1,130	1,150 – 1,200

304 stainless steel was selected as a base metal. Schematic diagram of the shear strength test specimen is shown in Figure 1. The specimens were polished to a particular roughness, and then washed ultrasonically in acetone. The shape of this specimen is designed much simple compared to the conventional shear strength test specimen. The mechanical properties of this specimen had already been evaluated and confirmed that identical joint strength were obtained for this specimen and the conventional shear strength test specimen. The specimens for corrosion test were prepared same as 304 stainless steel in other shape.

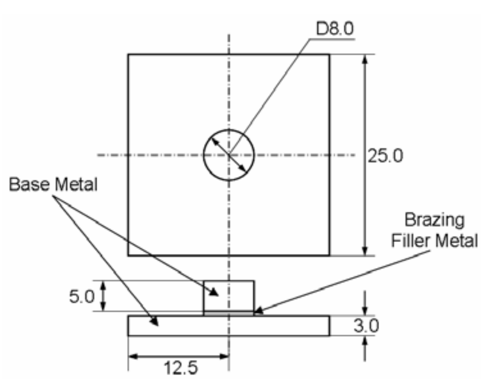

Figure 1 Schematic diagram of shear strength test specimen.

TB-4025 was selected as typical Fe-Cr based filler metal composition for this investigation. Brazing was done under the protective atmosphere, in vacuum and in dry hydrogen. Shear strength test specimens were brazed in vacuum furnace and corrosion test specimens were brazed in continuous hydrogen furnace. Brazing temperatures was 1,130°C and brazing time was fixed in 10 min at the elevated temperature.

Cross-section of the brazed joints was observed by optical microscope. Elemental distributions at the brazed joint were analyzed by electron probe micro analyzer (EPMA) examinations.

The joint strength was evaluated by the shear strength test. Image and schematic diagram of the shear strength test jig is shown in Figure 2. The crosshead speed was set to 1 mm/mm, and the test was performed at room temperature. The shear strength was determined as given in the equation below.

$$Shear\_Strength(MPa) = \frac{Maximum\_Load(kgf)}{Brazed\_Area(mm^2)}$$

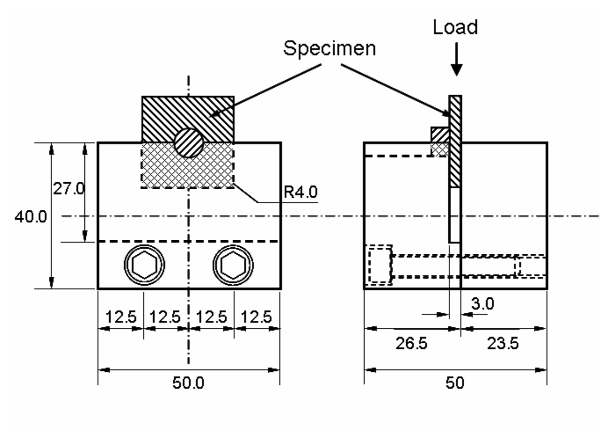

Figure 2 Image and schematic diagram of shear strength test jig.

Hardness at the interface of brazing joint was measured by micro Vickers hardness tester.

Corrosion resistance of brazing filler metals was estimated by dipping test and salt spray test. Specimens of the dipping test were prepared by melting 500mg brazing filler metal on the 304 stainless steel plate under protective atmosphere. Then the specimens were exposed to corrosive solutions, 5% of sulfuric acid, 5% of nitric acid, 5% of hydrochloric, 5% of sodium hypochlorite and 5% of aqueous ammonia, for 72 hours. Corrosive degree was evaluated by appearance and weight loss. Specimens of the salt spray test were made by brazing plate and fin for the 304 stainless steel heat exchanger. The test was done corresponding to JIS H 8052 7.1. Splay time was varied up to 168 hours and corrosive degree was evaluated by appearance.

Results and Discussion

Optical image of typical cross-sectional microstructure at the brazed joint with TB-4025 is shown in Figure 3. No joint failures such as porous and cracks were observed.

The beautiful fillet was formed at the edge with very fine microstructure which is assumed the effect of Mo contain. This microstructure is very different from traditional Ni brazing filler metals. In addition, cracks are easily formed in this size of fillet made of traditional Ni brazing filler metals but no cracks were found with Fe-Cr based filler metal.

Primary crystal Fe-α was formed at the brazed joint. Limited erosion to the base metal was observed. It is understood that the composition of the filler metals are similar to base metal so that interfacial reaction was controlled.

Back-scattered electron image and elemental distribution maps at the brazed joint is shown in Figure 4. Each element was finely distributed at the brazing filler metal layer. In special, P is well known elements to make hard and brittle intermetallic compound layer with Fe and which is caused to decrease joint strength. However, P was distributed in the brazing layer.

As a result of shear strength test, joint strength showed about 280MPa. The same test result of the joint strength of BNi-5 was about 310MPa. Fe-Cr based filler metal performed almost same joint strength as traditional Ni brazing filler metal.

As a result of micro Vickers hardness test at the fillet, hardness of primary crystal at the interface was Hv=280~470. Remained eutectic phase formed with fine microstructure at the fillet was Hv=220~480. Hardness distribution both primary crystal and eutectic phase was almost same. But measured hardness was quite wide range. It is because that microstructure was very small and it was almost impossible to measure each single crystal. However, it is understood that the hardness at the brazed joint was lower than traditional Ni brazing filler metal.

Corrosion test results by dipping test are shown in table 2. TB-4025 showed excellent corrosion resistance to sulfuric acid, nitric acid and aqueous ammonia. But appearance change and weight loss were observed against sodium hypochlorite. Sodium hypochlorite attacked a little but weight loss was not measured. As a result of dipping test, Fe-Cr based filler metal performs sufficient corrosion resistance to corrosive solutions except hydrochloric.

Comparing corrosion resistant to traditional Ni brazing filler metal, salt spray test was done to TB-4025, BNi-2 and BNi-5. An appearance of after the salt splay test was shown in figure 5. BNi-2 started corrosion remarkably during the test so that test was finished after 120 hours. After 168 hours of the test, TB-4025 and BNi-5 showed good corrosion resistance. Very little corrosion was observed for both filler metals but it is understood that corrosion resistance of TB-4025 is just as same as BNi-5.

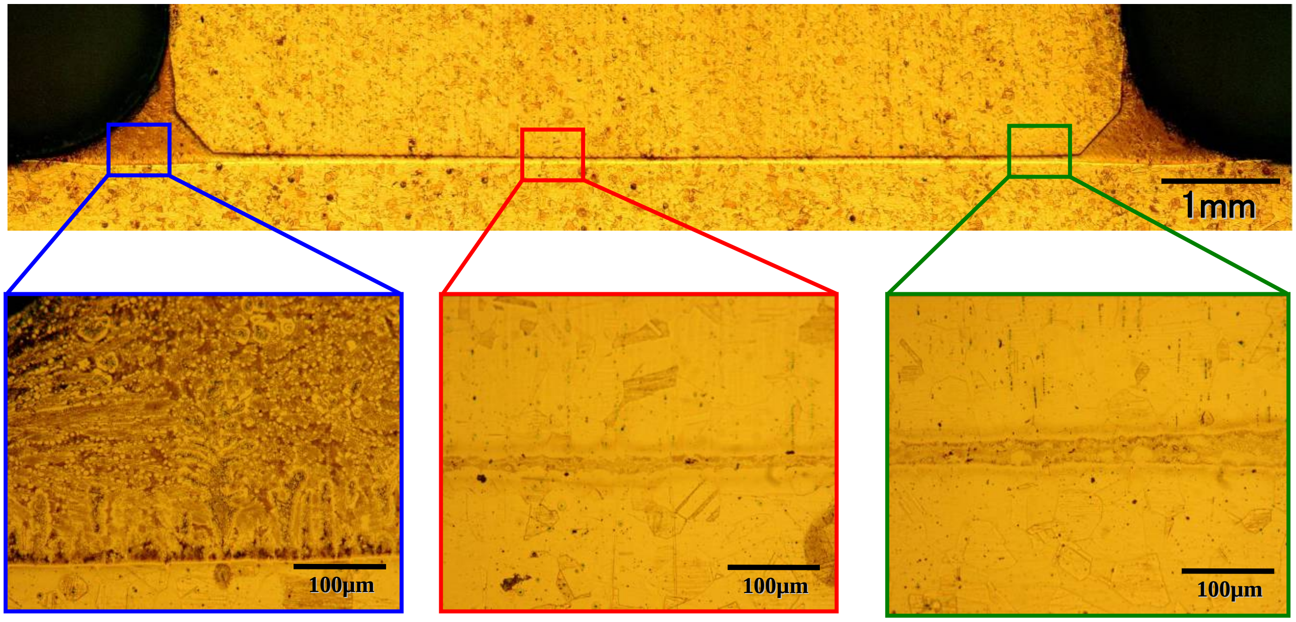

Figure 3 Typical optical image of the cross-sectional microstructure of TB-4025.

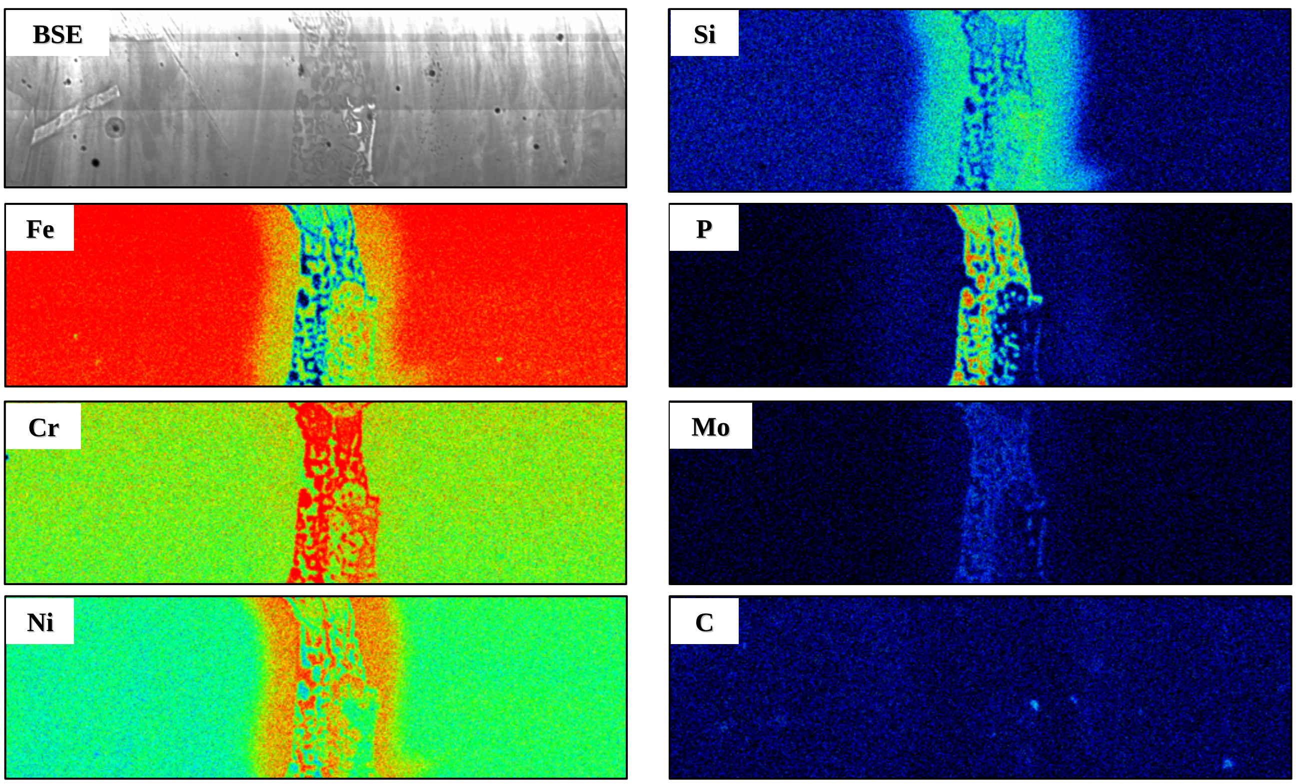

Figure 4 Elemental distribution maps of Fe, Cr, Ni, Si, P, Mo and C at the brazed joint.

Table 2 Corrosion test results by dipping test of TB-4025

Test Solutions	H_2SO_4(5%)	NHO_3(5%)	HCl(5%)	NaClO(5%)	NH_4OH(5%)
Weight loss(mg)	No change	No change	~10	Unable measure	No change
Results	Excellent	Excellent	Attacked	Good	Excellent

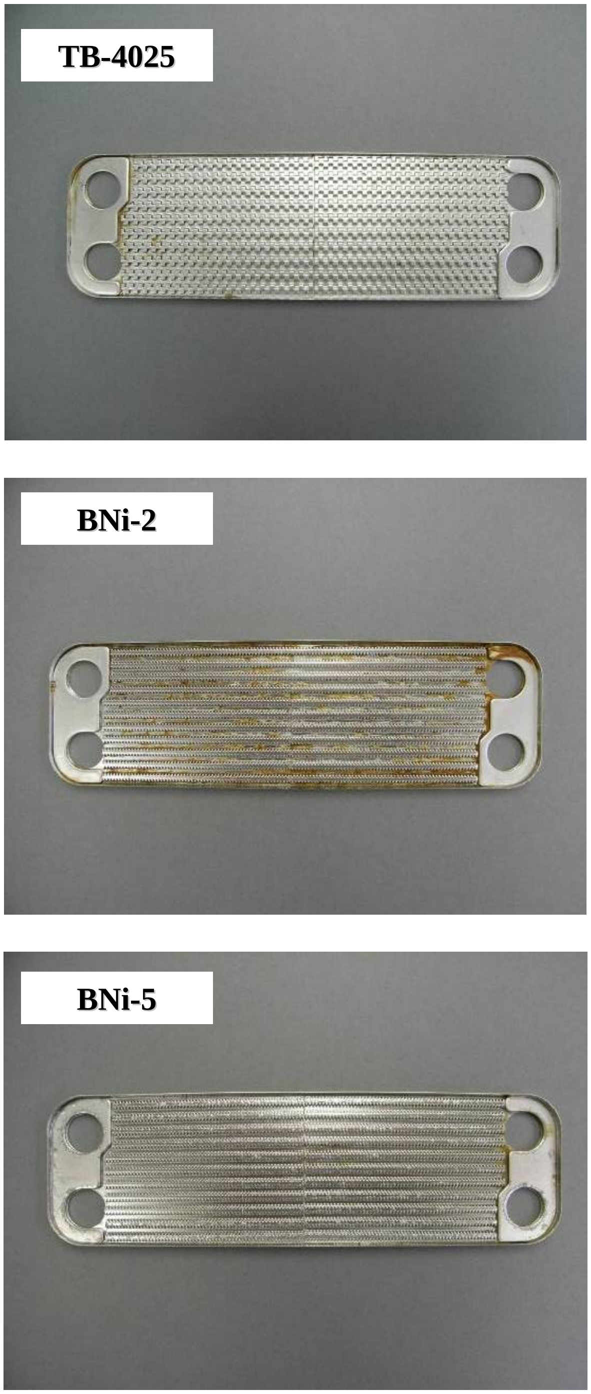

Figure 5 Appearance of after the salt splay test.

Conclusions

Newly developed Fe-Cr based filler metals were investigated and following conclusions were obtained.

1. Fine microstructure and primary crystal of Fe-α with no joint failures were formed at the brazed joint.
2. It is understood that Mo contain effected to form fine microstructure in the brazed layer.
3. Each element was finely distributed at the brazing filler metal layer and P didn't form brittle intermetallic compound layer.
4. Fe-Cr based filler metal performed sufficient joint strength as traditional Ni brazing filler metal.
5. Fe-Cr based filler metals performed good corrosion resistance compared to traditional Ni brazing filler metal.

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