Effect of Boron Content and Brazing Temperature on Braze ability of Foil-type Nickel-Based Brazing Filler metal

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The exhaust gas recirculation (EGR) cooler is an example of a product that utilizes stainless steel brazing. EGR cooler is a heat exchanger that cools exhaust gases, subsequently rendering these cooled gases useful for optimizing combustion. This application benefits extensively from the utilization of stainless steel owing to its excellent heat and corrosion resistance. Stainless steel brazing in this context is achieved through the application of various forms of brazing filler metal tailored to different brazing conditions and joint designs. Nickel-based brazing filler metals are classified into foil and powder forms. The employment of foil-type brazing filler metal is notable for its propensity to induce interfacial reactions even at temperatures below the conventional brazing temperature. Previous studies have shown a pronounced correlation between the boron content, a key constituent of brazing filler metal, and the brazing and liquidus temperatures. Heightened Boron content has been empirically proven to lead to decreased brazing and liquidus temperatures. Therefore, the effect of boron addition on brazing is investigated using coessential observations and assessments of joint strength. Ferritic stainless steel (SUS444) was used as the base metal while brazing metal is a nickel-based foil type augmented with varying boron concentrations. The brazing procedure entails the assembly of components using a stainless-steel jig, followed by brazing under vacuum conditions at 1050 ℃ for 10 min with a heating rate of 20 K/min. Post-brazing protocols encompass vaporizing binders at 600 ℃ for 15 min, succeeded by air cooling. Subsequent evaluations encompass visual inspections of the fillet, cross-sectional microstructural analyses conducted via optical microscopy, and tensile testing. This multifaceted investigation not only sheds light on the impact of boron content on the brazing process but also delves into the structural and mechanical integrity of the brazed joints.

Keywords: *car, strength, microstructure*

1. Introduction

The “exhaust gas recirculation (EGR) cooler” is the product in which stainless steel brazing occurs. This product functions as a heat exchanger and is designed to regulate the temperature of a portion of the high-temperature exhaust gases emitted from engines. This EGR cooler operates under the environments involving cooling water and exhaust gases, making it crucial to ensure the integrity and watertightness of the joints to prevent material degradation and leaks at joints. Because the EGR cooler operates under the environments where high-temperature exhaust gases are cooled and exposed to exhaust gas conditions, heat resistance and corrosion resistance are essential material properties. Consequently, vacuum brazing using stainless steel with excellent heat and corrosion resistance as well as powder-type nickel-based brazing filler metal with high melting points and remarkable corrosion resistance have been widely adopted.

However, the use of powder-type brazing filler metals involves mixing with binders during installation, causing concerns about furnace contamination owing to vaporization of volatile gases. Hence, transition from powder-type brazing filler metals to foil-type brazing filler metals gains momentum is desired, which allows enhanced control over brazing filler metal quantity and joint gaps and eliminates the need for binder removal.

Incorporating boron becomes necessary during the fabrication of foil-type brazing filler metals, the addition of. Past studies have revealed that during vacuum heating brazing of ferritic stainless steel (SUS444) and nickel-based foil-type brazing filler metal (MBF-20), boron diffuses into the base metal, spurring the formation of chromium borides. This compound formation reduces the chromium concentration in the brazed region, resulting in the formation of a chromium-depleted layer with reduced corrosion resistance. However, a 0.5% boron addition obviates the formation of such a chromium-depleted. Furthermore, experiments with foil-type nickel-based brazing filler metal (MBF-68) divulge that increased boron correlates with decreased brazing temperatures.

Herein, a considerably cost-effective ferritic stainless steel was chosen as the base metal over the pricier austenitic stainless steel. By employing foil-type nickel-based brazing filler metal with slight variations in boron content up to 0.5%, the brazing behavior below the conventional brazing temperature (1050 °C) was examined through cross-sectional microstructure observation and tensile testing.

2. Experimental Method

2.1 Material

Ferritic stainless steel (SUS444) was used as the base metal, and four types of foil-type nickel-based brazing filler metal (MBF-68) with varying amounts of boron addition were utilized as brazing filler metals. MBF-68 is an amorphous foil-type brazing filler metal with boron added into the 613 alloy. The conventional brazing temperature of 1050 °C was determined based on the liquidus temperature of the 613 alloy, measuring at 1030 °C. The chemical

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composition of the base metal is shown in Table 1, and that of the brazing metals is shown in Table 2.

Table 1 Chemical composition of the base material

Material	composition(%)								
SUS444	C	Si	Mn	P	S	Ni	Cr	Mo	Fe
	≦0.025	≦1.00	≦1.00	≦0.04	≦0.03	≦0.60	17.00~ 20.00	1.75~ 2.50	Bal

Table 2 Chemical composition of the brazing material

Material	composition(%)				
	Cr	Si	B	P	Ni
MBF-68	29.04	3.86	0.0002	6.24	Bal
MBF-68A	29.47	3.99	0.680	5.37	Bal
MBF-68B	29.26	4.08	0.2383	5.34	Bal
MBF-68C	29.08	4.09	0.3951	5.35	Bal

2.2 Brazing Specimen Preparation

A schematic diagram of the test specimens for cross-sectional microstructure observation is presented in Figure 1. Stainless steel was cut using a high-speed cutter, then joined with the brazing filler metal and anchored using SUS fixtures. A schematic diagram of the test specimens for tensile–shear testing is shown in Figure 2.

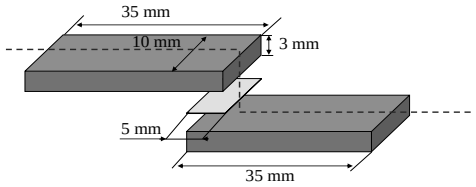

Figure 1 Schematic diagram of the test specimen for cross-sectional microstructure observation.

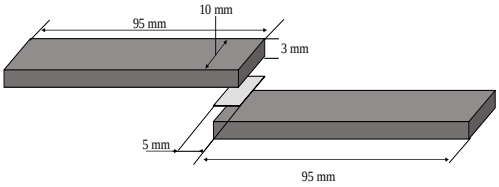

Figure 2 Schematic diagram of the test specimen for tensile-shear testing.

2.3 Brazing Conditions

The brazing temperature conditions are presented in Table 3. Vacuum brazing involved a heating rate of 20 K/min, with a 15-minute hold at 600 °C for binder vaporization. Following a 10-minute brazing temperature retention, the specimen was air-cooled. The heat cycle is illustrated in Figure 3. Herein, to facilitate comparative experiments with powder-type brazing filler metals, binder removal was performed during the brazing of the filler metals.

Table 3 Brazing temperature conditions

Specimen shape	Brazing Temperature (℃)
Specimen1	1050
Specimen2	1050
Specimen1	1025
Specimen2	1025
Specimen1	1000
Specimen2	1000
Specimen1	975
Specimen2	975

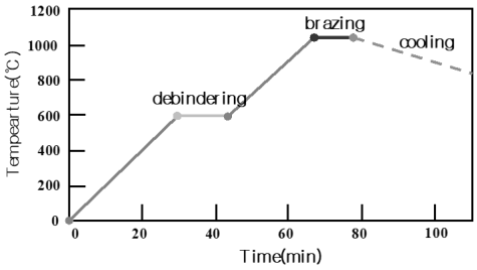

Figure 3 Brazing heat cycle

2.4 Specimen Preparation for Observation

The brazed test specimens were cut along the dashed line indicated in Figure 1 using a medium-speed cutter. The cutting positions were set at the center. After cutting, specimens underwent epoxy resin fixation and mirror polishing using waterproof abrasive papers (#400, #800, #1200, and #2000 grits) and diamond slurries (9μm, 3μm, and 1μm). This enabled cross-sectional microstructure observation using an optical microscope.

Additionally, cross-sectional microstructural images were analyzed using ImageJ to calculate the ratio of nonbonded areas.

2.5 Specimen Preparation for Tensile Testing

Brazed test specimens underwent tensile testing using an mechanical universal testing machine (INSTRON 3367). Stress calculation utilized a 5 mm × 10 mm nickel-based foil-type brazing filler metal with the formula $T = Q/A$.

Tensile speed was set at 1.00 mm/min.

3. Experimental Results and Discussion

3.1 Results of Optical Microscope Observation of Cross-Sectional Microstructure

Figure 4 presents a graph depicting the percentage of nonbonded areas against each brazing temperature and boron addition. A comparative representation of fillet area with varying boron addition at a brazing temperature of 1050 °C is presented in Figure 5. Figure 4 indicates a slight upswing in minor joint defects as boron content reduced at a brazing temperature of 1050 °C. However, all values remained below 3%, indicating minimal bonding defects and a high adhesion density. Furthermore, Figure 5 indicates a proportional augmentation in fillet area with escalated boron content, indicating that boron facilitated the formation of the fillet area, possibly related to wetting behavior.

At a brazing temperature of 1025 °C, similar trend results were obtained for MBF-68B as observed at 1050 °C. However, MBF-68 and MBF-68A exhibited ~20% joint defects, contrasting with the suitability of MBF-68B and MBF-68C as filler metals at 1025 °C. At brazing temperatures of 1000 °C and 975 °C, MBF-68 evidenced joint defects exceeding 70%. In contrast, MBF-68C, despite its minute 0.5 mass% boron content, exhibited lower joint defect rates even at a brazing temperature of 975 °C. Additionally, MBF-68 demonstrated an increasing joint defect trend as brazing temperature decreased, implying that the addition of boron reduced the joint defect rates. This suggests that trace boron addition facilitates interfacial reactions, heightening bonding affinity to mitigate joint defects.

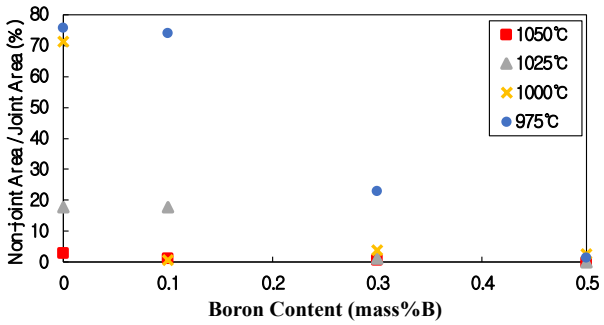

Figure 4 Non-bonded areas with respect to each brazing temperature and boron content for SUS444/MBF-68.A.B.C specimens.

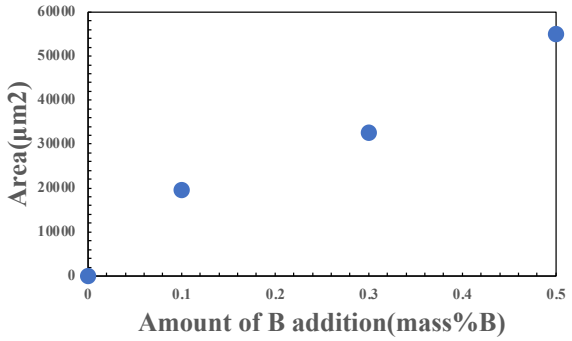

Figure 5 fillet area at a brazing temperature of 1050°C for the SUS444/MBF-68 specimens.

3.2 Tensile Test Results

Figure 6 presents a graph illustrating the variations in tensile–shear strength with brazing temperature and boron addition. The graph illustrates distinct trends: at brazing temperatures of 1050 °C and 1025 °C, increased boron content correlated with decreased tensile–shear strength. However, at a brazing temperature of 975 °C, an increasing trend in the tensile–shear strength was observed with increasing boron content. At a brazing temperature of 1000 °C, minor differences in the tensile–shear strength were observed with varying boron content. The addition of boron at 1050 °C likely prompted the formation of chromium borides in the residual eutectic, altering the mechanical properties, including binding energy with other phases in the residual eutectic, leading to a reduction in the tensile–shear strength compared to MBF-68 at 1050 °C.

In this experiment, the installation size of the foil-type filler metal for stress calculations was unified at 5 mm × 10 mm for the fracture area. This uniformity affects the difference in void fractions shown in Figure 4 and the formation of the fillet region, thereby influencing the slope of the shear–tensile strength. Specifically, at a brazing temperature of 1050 °C, heightened boron content led to an expanded joint area, causing an underestimation of the area term in stress calculations. Conversely, at a brazing temperature of 975 °C, an increase in the area term in stress calculations owing to heightened boron content could contribute to the observed trend in Figure 6.

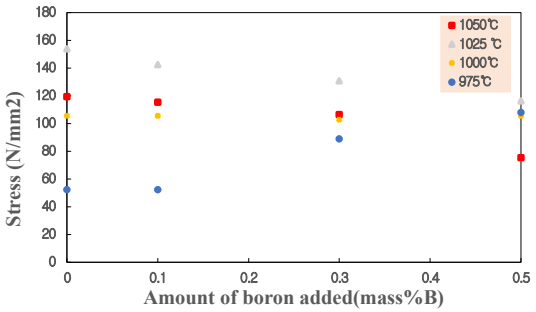

Figure 6 Tensile-shear strength at various brazing temperatures (SUS444/MBF-68.A.B.C)

4. Conclusions

There is an increasing interest for replacing powder-type brazing filler metals with foil-type brazing filler metals that allow brazing below conventional brazing temperatures and reduce furnace contamination. However, limited research has been conducted on the effects of boron added during the fabrication of foil-type brazing filler metals. Therefore, this study investigated the brazing behavior under low-temperature conditions with varying boron content. The following results are obtained:

(1) Boron addition induces accelerated interfacial reactions. Moreover, 0.5% boron addition to MBF-68 enables bonding under brazing conditions at 975 ℃ with a holding time of 10 min.

(2) A decrease in brazing temperature increases the joint defect rates.

(3) the shape of the residual eutectic varies with decreasing brazing temperature.

(4) At brazing temperatures of 1050 °C and 1025 °C, an increase in boron content affords a decreasing trend of the maximum shear strength.

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