Manufacturing of exhaust gas recirculation (EGR) heat exchanger (cooler) for automotive use using an Oxynon® furnance

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This paper presents to introduce a new methodology (brazing method) for manufacturing Exhaust Gas Recirculation (EGR)-Coolers.

An EGR-cooler is a heat exchanger that cools the exhaust gas down to an appropriate temperature before returning the partial exhaust gas emitted from the engine back into the engine again. An EGR-cooler consists of a component where the exhaust gas passes, as well as a water-cooling compartment where the exhaust gas is cooled down.

Because the component where the exhaust gas passes needs to be capable of efficient thermal diffusion, it has a group of fins which are made of processed thin stainless steel plates in a complex shape in order to reduce the flow rate of gas. The water-cooling compartment also has a feature to reduce the flow rate of gas.

Both of the above compartments cool down the exhaust gas by contacting each other through the thin stainless plate. In order to mold the structure of these compartments, many assembling parts are connected each other by brazing. For the brazing, high-temperature brazing filler metal, which is generally nickel filler alloy, is used. For the base metal, austenite-stainless steel is used in order to enable it to endure the exhaust gas circulation. In order to braze these metals, vacuum furnaces are generally used.

However, the method we are going to introduce in this paper does not use a vacuum furnace, but a continuous gas atmosphere furnace (Oxynon furnace), which has a unique structure (Oxynon atmosphere).

In this study, we would like to introduce our knowledge, gained through this research, of manufacturing technology of EGR-coolers using Oxynon furnaces.

1 Introduction

An EGR-cooler is structured by a combination of stainless steel (austenite) and nickel brazing filler metal (BNi-5, Ni-Cr-Si-P, etc.). The heating temperature for brazing is generally over 1000°C.

It is possible to observe some basic research presentations which are related to the EGR Cooler manufacturing. [1], [2], [3], [4], [5], [6]

In these studies, austenite-stainless steel plates were mostly used for the base metal and BNi-5, as well as newly developed Ni and Fe were used for the brazing filler metal. Particularly, the brazing filler metal made of Ni-Cr-Si-P was used in all of the above mentioned studies and it was highly evaluated.

Vacuum heating was the heating method for brazing in those studies.

Referring to those past studies, we decided to use the brazing filler metal made of Ni-Cr-Si-P in this study. For this research, ferrite-stainless steel for the base metal was chosen, which has been recently developed for practical use.

In addition, as for the heating method, the Oxynon furnace was chosen instead of the vacuum furnace, which has been generally used. Using the new heating method, the brazing properties was evaluated and aimed to obtain the basic knowledge on the manufacturing of EGR-coolers.

In this study, the stainless steel (ferrite) and nickel brazing filler metal were heated at a high temperature. Prevention and reductive reaction of the oxidation of the base metal and the brazing filler metal were essential factors while brazing.

Oxynon furnace has sufficient properties to meet the above criteria. The followings are the primary properties:

(1) All of the furnace's internal structures are made of high-purity graphite. Neutral gas (nitrogen or argon) is used for the internal atmosphere, so the internal oxygen partial pressure can be reduced to below 10^{-15} Pa. Therefore, there would be no contamination with the brazed products.

(2) This is a mesh belt-type continuous furnace. Because C/C composite belt is used for the mesh belt, a continuous feed under a high-temperature heating at up to 2600℃ is possible.

(3) The furnace is linearly structured by a preheating zone （evaporation of the binder）, a heating zone and a cooling zone. Each brazed product is continuously brazed by passing through these zones.

Due to the above properties, it can be said that the Oxynon furnace is sufficiently capable of manufacturing EGR-coolers.

Furthermore, in order to obtain the knowledge of the brazeability required for the EGR manufacturing using Oxynon furnace, we tested the following properties as well:

(1) Spreading factor (wettability) of brazing filler metal
(2) Mechanical properties (tensile shear strength, butt shear strength, joint's hardness distribution) of brazed joints
(3) Corrosion resistance of brazed joints
(4) Impact of heating atmosphere gas (Ar gas, N_2 gas atmosphere)

Details of the Oxynon furnace were presented at the previous conference LÖT 2010 [7].

Figure 1 Special specification OXYNON® FURNACE.

2 Experimental Procedures

2.1 Brazing filler metal

BNi-5 (Ni-Cr-Si) has been generally used for the brazing filler metal with EGR-coolers.
The reason for the choice is because BNi-5 does not contain boron (B) unlike the brazing filler metal made of nickel and it has better corrosion resistance compared to the brazing filler metal which contains boron in the case where corrosive gas needs to be processed such as EGR. Because boron is not contained, however, the melting temperature is high, which consequently requires a high brazing temperature, as well as brazing skills.
In the past few years, due to the nickel price hike, the consumption of nickel has declined and several new brazing filler metals have been developed, for example, a brazing filler metal made of Fe-base Fe-Cr-Ni-Si-P or Fe-Cr-Ni-Si-P-Mn-Cu, which has a reduced content of nickel.
In this study, among those available brazing filler metals, the one with Ni-Cr-Si-P was chosen, which has been well recognized as a brazing filler metal for EGR-coolers, and evaluated its brazeability. The brazing filler metal powders was mixed with a binder and made into a paste.

2.2 Base metals

Austenite-stainless steel (SUS304, SUS316) has been generally adopted for the base metal in the conventional EGR-coolers for diesel engines, to prevent the corrosion of the exhaust gas. However, ferrite-stainless steel has been recently used for EGR for gasoline engines. In this study, considering this fact, we determined to adopt ferrite-stainless steel (SUS430, SUS444) for the base metal.

2.3 Atmosphere gas

In the case where stainless steel is brazed in Oxynon furnace, argon gas is generally used. So far, we have also conducted brazing of stainless steel using argon gas. In this study, considering various conditions, we experimentally used nitrogen gas in addition to argon gas and evaluated various properties that could be impacted by the difference between those gases, such as wettability, joint mechanical properties, and corrosion resistance.

2.4 Wetting (Spreading) test

Wettability of the brazing filler metal is very important when it comes to the brazeability evaluation. For the measurement of wettability, as seen in Figure 2, we placed 0.1 gram of brazing filler metal (paste) on a stainless steel plate (30 mm × 30 mm ×t3 mm) and calculated the spreading factor (A) from the spreading area obtained after heating.
The spreading factor (A) was set to 1/2 of the x, y intercept length of an spreaded circle, due to the fact that the spreaded brazing filler metal becomes almost a round shape after the wettability test.
As for the brazing conditions to evaluate the impact on wettability, the heating temperature was set at three different points by adding 50°C to each liquidus temperature, which were 1080°C , 1130°C , 1180°C. The brazing time was gradually increased from 5 minutes to 15 and 30 minutes.
Also, the brazing temperature was set at a constant of 1130°C and wettability was evaluated when argon gas and nitrogen gas were used as atmosphere gas after 5, 15, 30 minutes of brazing time.
In addition, we examined the difference between Oxynon heating and vacuum heating by observing the T-shaped brazing joint's interface structure after heating for 15 minutes at 1130°C.

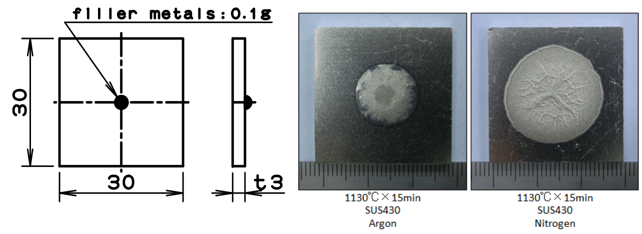


Figure 2 Wetting (Spreading) test piece and these specimen dimensions. Filler metal (paste state): 0.1 grams.

2.5 Joint strength

2.5.1 Lap shear test

Figure 3 shows the appearance of the test specimen that was used in the experiment (JIS Z 3192). In a tensile shear test with a lap joint brazing, the overlapped area would make a large impact on the shear strength. However, in this experiment, the overlapped area was configured as the same length as the plate thickness (t 1.0). After the experiment concluded, little deformation was found on the plate at the brazed joint. Thus, we considered that the value we obtained barely impacted the shape. About 0.025 grams of brazing filler metal was applied to the overlapped area. We chose both of the generic vacuum heating method and Oxynon heating method and adopted argon gas and nitrogen gas for the heating atmosphere to form a test specimen. The brazing temperature was set to 1130°C which is considered to be the appropriate temperature for the brazing filler metal (Ni-Cr-Si-P).

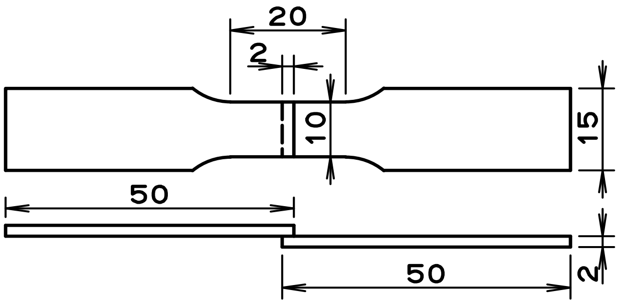


Figure 3 Tensile shear strength test specimen (JIS Z 3192) and these dimensions.

2.5.2 Butt shear test

Figure 4 explains the overview of the test specimen we used. We conducted brazing on a specimen where a stainless steel stick of Ø = 10 mm and h = 10 mm was placed on a stainless steel plate (SUS444, SUS430) of 30 mm × 30 mm × t6 mm. Brazing filler metal of 0.1 gram was applied between the stainless steel plate and the stainless steel stick. The same conditions from the wettability test were applied to the brazing conditions, in which the heating temperatures were 1080°C, 1130°C, 1180°C and the heating times were 5 minutes, 15 minutes, 30 minutes. In order to calculate the maximum shear stress, the brazed test specimen obtained was fixed to the jig indicated in Figure 5 and a compressed load was added.

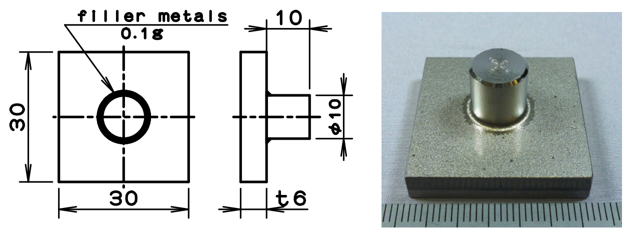


Figure 4 Butt shear strength test specimen and these dimensions.

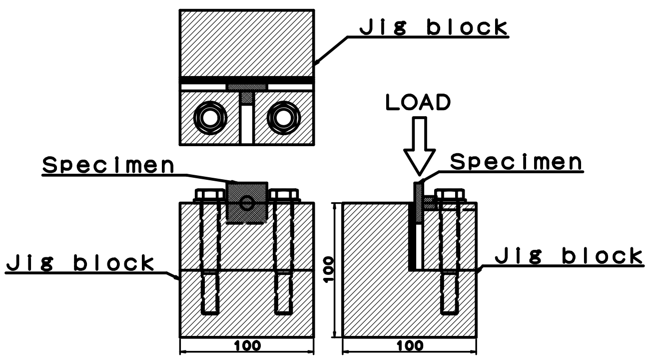


Figure 5 The jig equipment for the butt shear strength test specimen.

2.5.3 Corrosion test

Using the test specimen obtained from the wettability test, a salt spray test (5% salt water) was conducted. Salt water was sprayed for up to 40 hours and the specimen's surface was examined after the test.
As for the test conditions, argon gas and nitrogen gas were adopted for the atmosphere, a stainless steel plate (SUS430, SUS444) was used for the base metal and Ni-Cr-Si-P was used for the brazing filler metal.

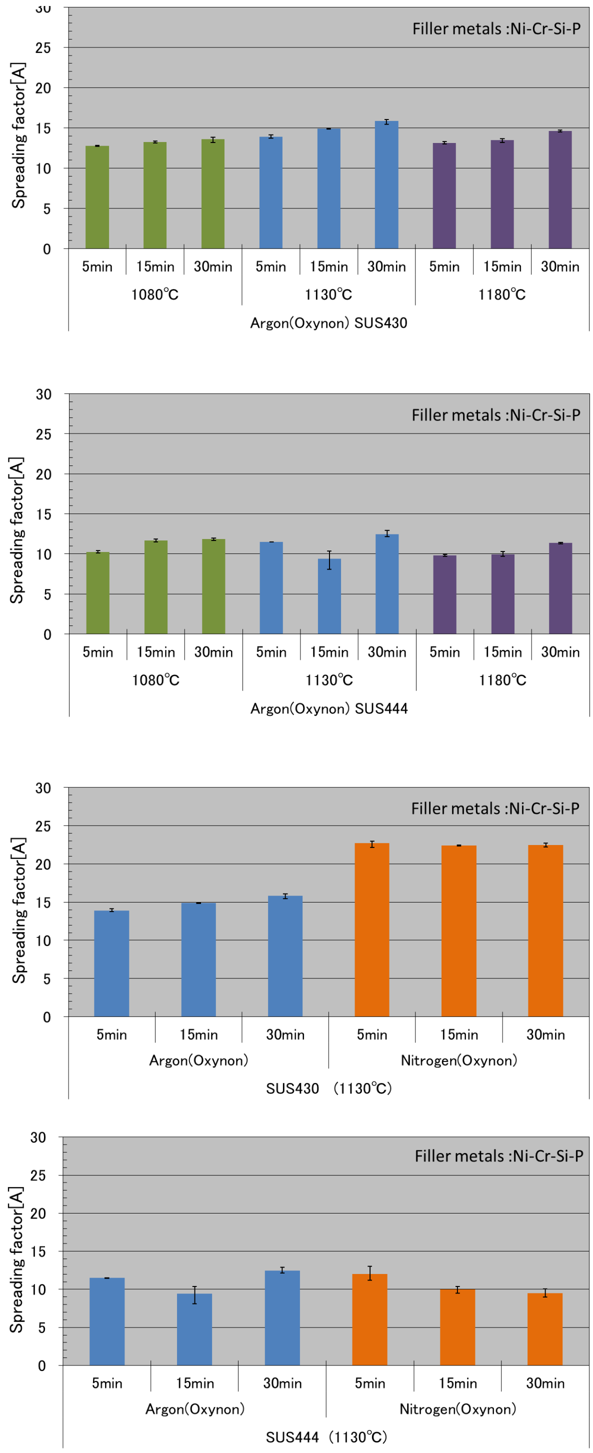
3 Results and discussions

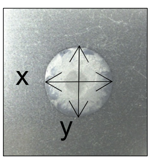
3.1 Spreading and wetting

The spreaded brazing filler metal became almost a round shape as seen in Figure 6. The applied brazing filler metal evenly spread out in x-axis and y-axis directions. Therefore, it can be considered that the brazing filler metal has good wettability.
In the case where Oxynon furnace and argon gas atmosphere are adopted, the wettability is barely impacted by the heating temperature changes even if it was increased from 1080°C to 1180°C. However, we found that the spreading area tends to get slightly bigger as the brazing time at each temperature gets longer than 5 minutes. As for the base metal, the spreading area when SUS430 is used was about 20-30% bigger than that when SUS444 was used.
Furthermore, as for the spreading area when argon gas and nitrogen gas were used in an Oxynon furnace, SUS444 did not generate a big difference but SUS430 had about 30-40% bigger spreading area when nitrogen gas was used for the atmosphere, compared to argon gas. We will further examine these differences on the spreading area in the future. These results indicate the feasibility of the use of nitrogen gas for the atmosphere gas in Oxynon furnace in order to have better wettability, instead of limiting the use to argon gas. Figure 7 explains the observation results of T-shaped brazed joint's structures in a vacuum furnace and an Oxynon furnace. On the brazed joint's interface, we found that the base metal was melted (erosion) by the fused brazing filler metal. The level of erosion does not largely change between Oxynon heating and vacuum heating. In both furnaces, fillets were favorably formed.

3.2 Joint strength

From the results of the tensile shear strength test, it is clear that there was almost no difference between vacuum furnace and Oxynon furnace on the strength. Although the difference between argon gas atmosphere and nitrogen gas atmosphere was subtle, it was found that nitrogen gas atmosphere would increase the strength with both of Oxynon heating and vacuum heating. As for the butt shear strength, there was almost no impact from the difference on the heating temperature and the heating time with Oxynon furnace. Also, there were no big differences between argon gas atmosphere and nitrogen gas atmosphere with Oxynon furnace.





Spreading factor = [A]

$$A = \frac{x+y}{2}$$

Figure 6 Wetting (Spreading) test results. Spreading ratio comparison of the defferent temperature, time and atmospher gas.

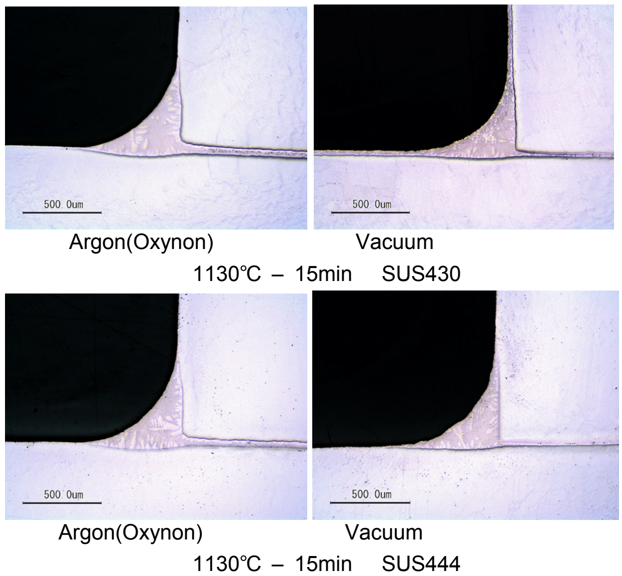


Figure 7 Metallographic examination of T-shaped brazed joints interface. The difference of heating atmosphere (Oxynon furnace, Vacuum furnace) and base metal.

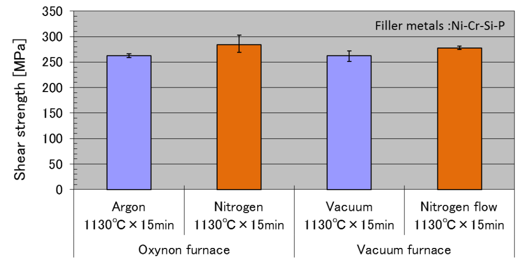


Figure 8 Tensile shear strength test results. Difference of heating atmosphere and brazing conditions (temperature, time.

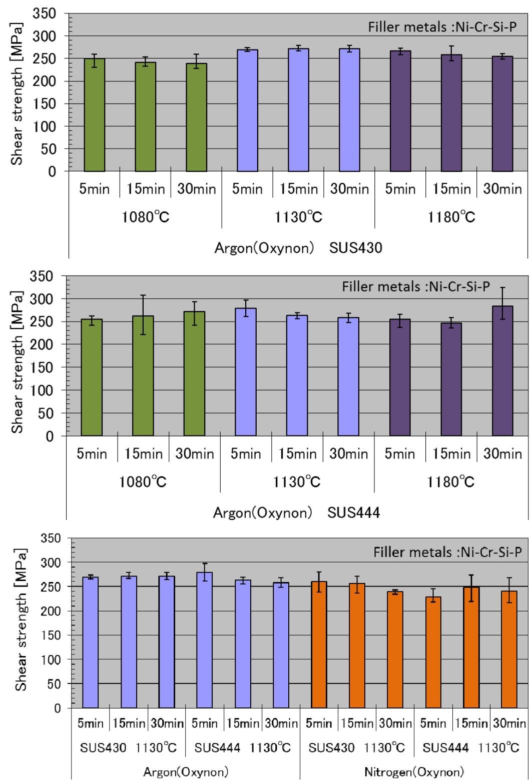
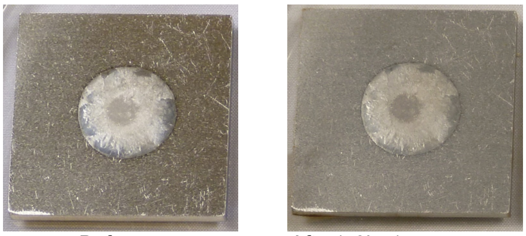


Figure 9 Butt shear strength test results. The effect of brazing condition on the temperature,time and atmosphere (argon, nitrogen gas).

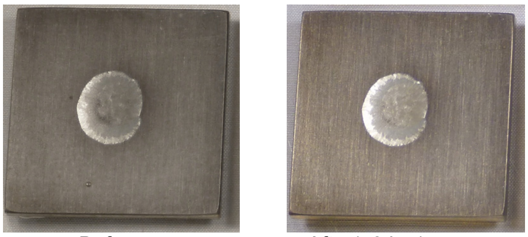
3.3 Corrosion test

Figure 10 shows the transition of corrosion with the wettability test specimen before/after for 40 hours salt spray test.
Even though a slight discoloration was observed on the surfaces of the brazing filler metal and the base metal, this type of discoloration can be easily removed through a simple lapping treatment. No corrosion which could incur a weight loss was found.



Before After(40hrs)

SUS430 Argon (Oxynon) 1130℃ – 15min



Before After(40 hrs)

SUS444 Argon (Oxynon) 1130℃ – 15min

Figure 10 Spreading test piece surface after corrosion testing. Salt water spray corrosion test. (40 hours).

4 Conclusion

Not using vacuum furnaces that has been generally adopted for the manufacturing of EGR-coolers, Oxynon continuous heating furnace that we developed by ourselves was used and examined various properties required for the manufacture, such as spreading factor (wettability), mechanical properties (tensile shear test, butt shear test, hardness distribution), corrosiveness, etc. through basic tests, from which we successfully obtained necessary results. After considering these test results, we tested the manufacturing of EGR-coolers using Oxynon furnace in a combination of ferrite-stainless steel and a brazing filler metal made of Ni-Cr-Si-P.
As a result, we are confident that there would be no problems in manufacturing EGR-coolers using Oxynon furnace due to its preferable properties.
In addition, we conducted various tests to examine brazeability (wettability) test, tensile shear test, Butt shear test, hardness distribution, corrosion test) with each material of brazing filler metal (BNi-5, Ni-Cr-Si-P, Fe-base) required to manufacture EGR-coolers using austenite-stainless steel. We obtained preferable results from all of these tests as well. From all of the above results, we are pleased to say that there would be also no problems for the manufacture of EGR-coolers using Oxynon furnace when austenite-stainless steel is adopted for the base metal.

5 References

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