

Chapter 46

Research on the Fluxless Brazing of Aluminum Air Cooled Oil Cooler

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Abstract Controlled atmosphere brazing of aluminum air cooled oil cooler without flux was investigated. The materials of the middle plates and the mounting plates used in the research are fluxless brazing alloy with five layers. The materials of the other parts are conventional 3003 single layer aluminum alloy. After assembling, the oil cooler is put into the CAB brazing furnace, without appended any flux on it. After brazing, the surface of the oil cooler is dark, and the brazing fillets between the middle plates can hardly be seen from the outside of the oil cooler by naked eyes. The metallographic analysis of the sections of the oil cooler shows that the fillets of the brazing seams near the outside of the oil cooler are very small, but the fillets of the brazing seams of the interior are very big. This phenomenon shows that the molten brazing filler flows from the outside of the oil cooler to the inside during brazing. The SEM and EDS analysis results shows that a thin flux layer is covered on the surface of the middle plates of the outside of the oil cooler. The existence of the flux layer effects the oxide removing ability of the fluxless brazing materials. Consequently, the wetting and spreading abilities of the brazing filler on the surface of the aluminum alloy after melting are influenced.

Keywords Air cooled oil cooler · Fluxless CAB brazing · Flux adhesion · Wetting ability · Reaction

46.1 Introduction

There exists an oxide layer on the surface of the aluminum alloy with the thickness of about 10 nm at the room temperature at the atmosphere [1]. When the aluminum alloy is heated to the brazing filler melting point, the thickness of the oxide is

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rapidly increased to several hundred nanometers. The structure of the aluminum oxide is very dense, and the melting point of the oxide is as high as 2050 °C, so it is very hard to broke during brazing. The existence of the oxide layer severely effects the wetting ability of the brazing filler. In a word, the sticking point of aluminum brazing is removing the oxide covered on the surface of the aluminum alloy during brazing.

The state-of-the-art brazing processes of aluminum oil cooler are controlled atmosphere brazing(CAB) and vacuum brazing (VB) [2].

During CAB brazing, Nocolok flux ($KAlF_4 + K_3AlF_6$) is adopted to remove the oxidation film, which covers on the surface of the aluminum parts before brazing. CAB brazing has the advantages of high efficiency and larger-gap adaptability between parts, but the disadvantages are also very clear. The first disadvantage is flux remaining on the inner surface of the product after brazing, which effects the cleanliness of the oil cooler [3, 4]. The second disadvantage is also related to flux remaining. When the brazing gap between parts is very big, the brazing filler is not enough to fill in the gap, so the molten flux fill in the gap. This defect is not able to be detected during manufacture process. When the oil cooler is installed on the car and running on the road, the flux adhered on the brazing seam will broken off under work force and libration, and makes the oil cooler leak and the engine failed.

During vacuum brazing, the atmosphere force is controlled below 5×10^{-3} Pa by vacuumizing. When the aluminum brazing alloy is heated above 400 °C, the Mg element in the brazing filler diffuses to the surface of the aluminum alloy, and reacts with the oxidation film. Vacuum brazing has the edge of high appearance quality [5–7], and high Mg content is allowed in the core layer, which increases the strength of the Al alloy. But vacuum brazing has the disadvantages of high parts cleanness, low efficiency and high cost.

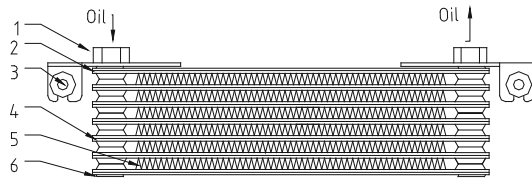
The fluxless CAB brazing means adding no flux after assembling, and putting the products directly into the CAB brazing furnace to braze. The mechanism of the fluxless brazing is nearly the same as vacuum brazing. Both of them use the oxide removing ability of Mg element to remove the oxide covered on the surface of the aluminum alloy during brazing. But the difference is that the structure and chemical content of the fluxless CAB brazing material is optimized, so fewer Mg element is needed, and the request of the atmosphere is not so strict. The fluxless CAB brazing both have the advantages of conventional CAB brazing and vacuum brazing, for instance, cleanliness, high efficiency and no flux remained after brazing.

46.2 The Product Structure and Experimental Materials

46.2.1 The Product Structure

The mechanism of the air cooled oil cooler is using air to cool the engine oil. The main parts of the product are flanges, upper plate, mounting plate, middle plates, fins and lower plate. All of these parts are joined together by brazing. When the oil

Fig. 46.1 Schematic diagram of the structure of the oil cooler 1 flange, 2 upper plate, 3 mounting plate, 4 middle plate, 5 fin, 6 lower plate



cooler is working, the engine oil flows into one of the flange and flows out from the other flange. The engine oil flows between two middle plates when it flows inside of the oil cooler, so the heat of the engine oil is transferred to the atmosphere by fins and plates. There are two sorts of the fins in the oil cooler. One sort of the fins are located at the inside of the oil cooler, and cannot be seen from the outside. They are used as disordering the flowing engine oil and transferring the heat out. The other sort of the fins can be seen from the outside of the oil cooler. They are used to transfer the heat from the middle plates to the atmosphere. The structure of the oil cooler is shown in Fig. 46.1.

46.2.2 Experimental Materials

The materials of the middle plates and the mounting plates are special multi-layers. Both of the surfaces of the middle plates are covered with brazing filler metal, but there is only one surface of the mounting plate covers with brazing filler metal. The materials of the other parts are conventional 3003 aluminum alloy, without brazing filler metal layer.

The materials of the different brazing methods are mainly the difference of the aluminum multi-layers. For instance, if normal CAB brazing (Nocolok brazing) is chosen, the middle plates are usually three-layer aluminum alloy, using 4045 brazing alloy as cover layer with 3003 aluminum alloy as core layer. But if vacuum brazing method is chosen, although the middle plates and mounting plates are also three layers, but the chemical content makes a big difference. The brazing layers contain about 1.0–2.0% Mg, which is strictly controlled in Nocolok brazing.

The five-layer structure is usually adopted in the fluxless brazing alloy. The number of the layers is larger, the easier to add and control alloy element, but the cost is also increased, so the five-layer structure is the best choice. As mentioned before, the mechanism of the fluxless CAB brazing is like vacuum brazing, the Mg element is added in the brazing materials as alloy element to remove the aluminum oxide covered on the surface of the aluminum. The Bi element is also added to increase the wetting ability of the brazing filler metal.

The chemical content of the fluxless CAB brazing material which is called 9181 is shown in Table 46.1. 9181 alloy has five layers, which contains two top layers, two brazing layers and one core layer. Both top layers and brazing layers has high Silicon content, but the content of Si is much higher in the brazing layers.

Table 46.1 The chemical content of 9181

Element	Top layer	Brazing layer	Core layer
Si	4.25–5.2	11.0–13.0	0.60
Fe	0.25	0.25	0.70
Cu	0.25	0.25	0.05–0.20
Mn	0.10	0.10	1.0–1.5
Mg	0.05	0.30	0.05
Cr	0.10	0.05	0.05
Zn	0.05	0.10	0.10
Ti	0.05	0.05	0.05
Zr	–	–	0.05
Bi	–	0.05–0.20	–
Al	Bal.	Bal.	Bal.

During fluxless CAB brazing, when the product is heated to 400 °C, the Mg and Bi elements contained in the brazing filler begin to diffuse to the top layer, the diffusion speed of Mg and Bi is much higher when the temperature raises. When the temperature of the products raises to the brazing filler metal melting point, the brazing filler metal melts and flows to the direction of the top layer. Because the top layer is very thin, the erosion effect of the brazing filler makes the top layer melt. The ideal result is that the Mg and Bi elements diffuse to the surface of the aluminum on time and react with the oxidation film when the brazing layers and top layers are all melting.

The thickness of the top layer and the Mg and Bi content are the key know-how of the fluxless CAB brazing materials. If the top layer is too thin, the Mg and Bi elements diffuse to the surface of the aluminum ahead of time. The Mg element removes the oxide but the brazing filler metal is not melted at the moment, so the surface of the aluminum re-oxidized before all of the brazing filler melting. When the brazing filler melts, the surface of the aluminum is not able to wetting the molten brazing filler.

If the top layer is too thick, the erosion function of the brazing filler is too weak to make all of the top layer melted, the brazing process must be failed either. Moreover, the Mg and Bi content of the brazing filler should be strictly controlled, The Mg content must be controlled less than 0.3%. The Mg content of the top layers should be controlled less than 0.05%.

46.3 Experiment Process

The fluxless CAB brazing materials are stamped into middle plates and mounting plates, and then assemble them with upper plates, fins, lower plates and flanges which are currently used in conventional CAB brazing. All of the parts are assembled together referring to the blueprint. After assembling, put the semi-manufactured products on the press machine to make the gap between parts much smaller.

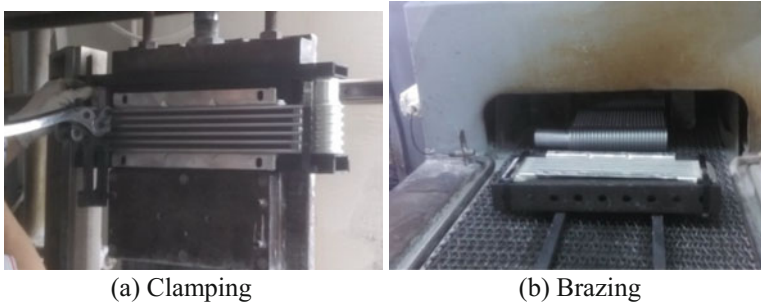


Fig. 46.2 Test process

After assembling and clamping, put the oil coolers directly into the CAB furnace to braze, without dipping or painting flux (Fig. 46.2).

The fluxless brazing oil cooler is put together with Nocolok brazing products in the CAB furnace. The CAB brazing furnace has 6 heating zones, and the brazing temperature of each zone is 250 ± 20 , 530 ± 20 , 580 ± 20 , 610 ± 10 , 625 ± 10 , 625 ± 10 °C. The mesh belt operating speed is 400–520 mm/min.

46.4 Results and Discussions

46.4.1 Analysis of the Appearance of the Oil Cooler

The appearance of the fluxless CAB brazing oil cooler is analyzed after brazing. The appearance of the oil cooler is shown in Fig. 46.3. The surface of the middle plates and the fins of the outside of the oil cooler is dark, even darker than Nocolok brazed products. The quality of the brazing seams is very bad. The brazing seams even cannot be seen from the outside of the oil cooler.

After cutting the product by saw, the appearance of the interior of the oil cooler is shown in Fig. 46.3c. The color of the inside surface of the oil cooler is brighter, and the brazing seam fillets are very full.

46.4.2 Metallographic Analysis

The microstructure of the brazing seam of the middle plate to the middle plate is shown in Fig. 46.4. The brazing seam fillet of the inside of the oil cooler is very big, but the fillet of the outside of the oil cooler is very small. Compared the residual brazing layer of the outside to the inside of the oil cooler, we conclude that the brazing filler flows from the outside of the oil cooler to the interior during brazing, as shown in red arrow in Fig. 46.4.

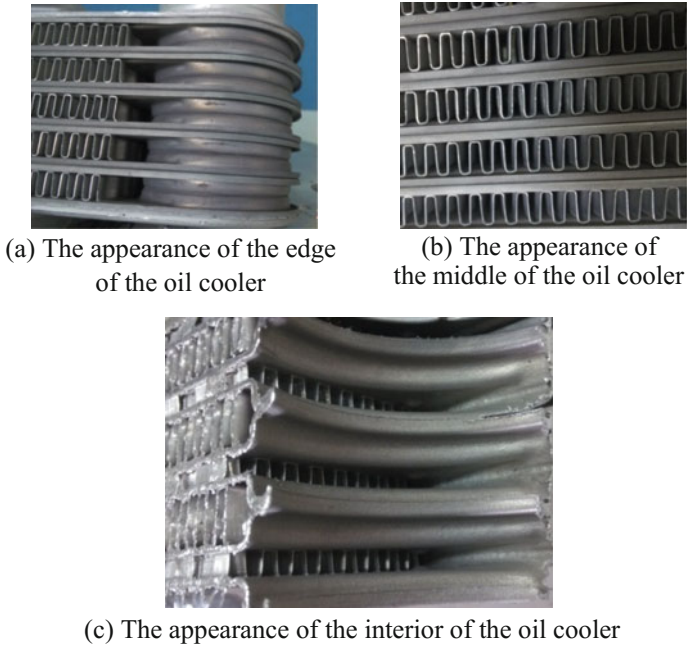
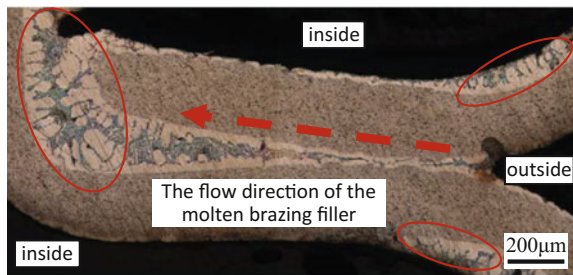


Fig. 46.3 The appearance of the oil cooler after brazing

Fig. 46.4 The brazing seam of the middle plates of the oil cooler



The brazing seam of the middle plate to the inside fin is shown in Fig. 46.5. The fillet of the brazing seam is very big, and the quality of the brazing seam is very excellent, without defects such as porosity and gaps.

The brazing seam of the middle plate to the outside fin is shown in Fig. 46.6. The fillet of the brazing seam is very small. Compared with the brazing seam of the inside of the oil cooler, we know that the quality of the brazing seam of the outside of the oil cooler is very poor, but the brazing seam of the interior is very good. The quality of the brazing seam may be influenced by the furnace atmosphere during brazing. The interior of the oil cooler is isolated relatively to the outside, so the

Fig. 46.5 The brazing seam of the middle plate to the inside fin

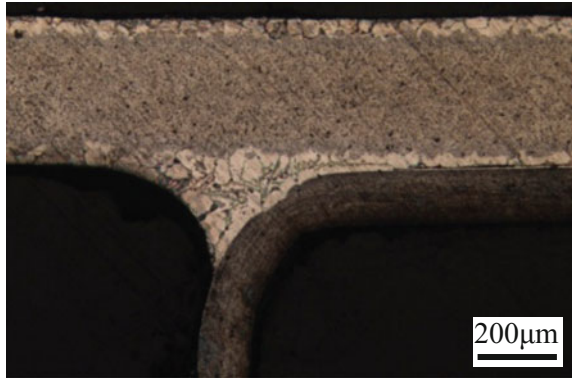
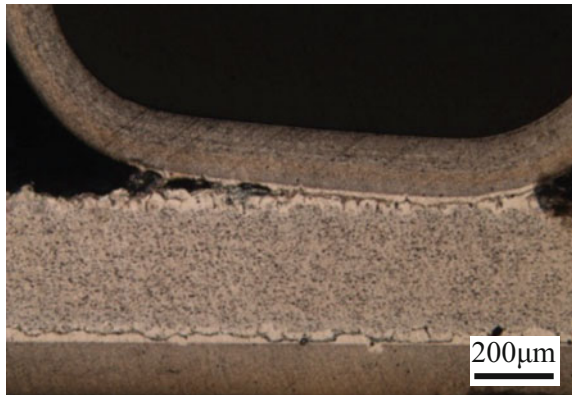


Fig. 46.6 The brazing seam of the middle plate to the outside fin

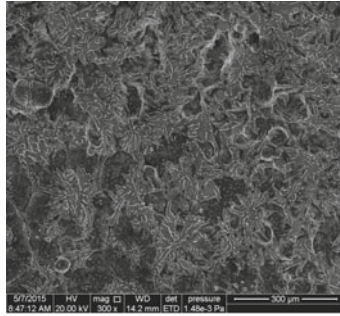


furnace atmosphere hardly effect the brazing process. But the outside of the oil cooler is contacted tightly to the atmosphere, so the brazing process is influenced by the atmosphere.

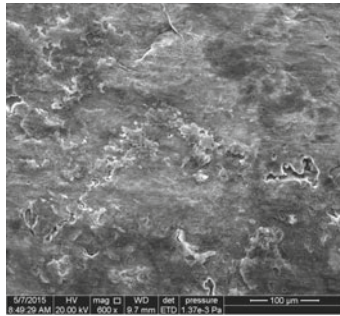
46.4.3 SEM and EDS Analysis

46.4.3.1 Analysis of the Appearance by SEM

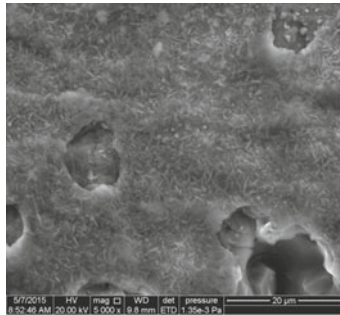
The morphologies the surface of the middle plates of the outside and the inside of the oil cooler by SEM is shown in Fig. 46.7. Figure 46.7a shows the surface morphology of the middle plate of the inside of the oil cooler. The brighter zone of the picture is Al-Si eutectic structure, and the darker zone is α -Al primary phase. These phases are typical after brazing in the aluminum brazing materials. The morphologies of the middle plate of the outside of the oil cooler are shown in



(a) The morphology of the middle plate of the inside of the oil cooler



(b) The morphology of the middle plate of the outside of the oil cooler(600X)

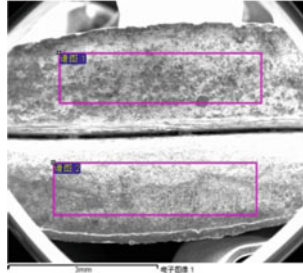


(c) The morphology of the middle plate of the outside of the oil cooler(5000X)

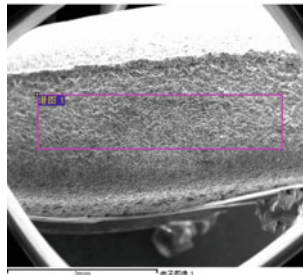
Fig. 46.7 The morphologies of the middle plates of the inside and outside of the oil cooler

Fig. 46.7b, c. When the magnification is 600 \times , the surface of the middle plate is flat and smooth, the Al–Si eutectic structure cannot be seen from the picture. When the magnification is 5000 \times , the morphology of the surface of the middle plate is changed. The surface of the middle plate covers with a layer with many white needle-like substances embedded in it.

Fig. 46.8 EDS analysis areas of the middle plates of the oil cooler



(a) EDS analysis areas of the outside of the oil cooler



(b) EDS analysis area of the inside of the oil cooler

46.4.3.2 EDS Analysis

The EDS analysis areas of the middle plates of the outside of oil cooler are shown in Fig. 46.8a. Two areas of $3\text{ mm} \times 1\text{ mm}$ are chosen to analyze the chemical content of the surface of the middle plates. An area of $3\text{ mm} \times 1\text{ mm}$ of the middle plate of the inside of the oil cooler is chosen to analyze the chemical content, as shown in Fig. 46.8b.

The EDS analysis results of the middle plates of the outside and inside of the oil cooler are shown in Table 46.2. The oxygen content of the middle plate of the inside is higher than outside of the oil cooler, it is concluded that the oxygen content is not the factor which effects the appearance of the oil cooler and reduces the quality of the brazing seam. Compared Table 46.2a, b, we can find that the surface of the middle plate of the outside of the oil cooler contains high K, F, Mg element, but the surface of the middle plate of the inside contains very little F, and contain no K element. We can infer that the dark appearance and poor brazing seams of the outside of the oil cooler are related to the existence of the brazing flux.

As is well-known, during conventional CAB brazing, the Mg element react with KAlF_4 flux at the brazing temperature, and generates MgF_2 , which has higher melting point. and effects the oxide removing ability of the KAlF_4 flux, so the Mg content in the brazing materials is strictly controlled. On the contrary, the existence of the KAlF_4 flux in the brazing furnace effects the oxide removing ability of the

Table 46.2 EDS analysis results of the middle plates of the outside and inside of the oil cooler

Element	Area 1	Area 2
(a) The chemical content of the middle plate of the outside of the oil cooler		
O	9.45	7.56
F	22.15	18.67
Mg	4.23	2.99
Al	44.28	47.98
Si	14.47	18.23
K	3.70	2.85
Mn	–	0.33
Element	Area 1	
(b) The chemical content of the middle plate of the inside of the oil cooler		
O	22.42	
F	0.74	
Mg	0.15	
Al	59.15	
Si	16.47	
K	0.00	
Mn	0.31	

Mg element which contained in the brazing materials when it diffuses to the surface of the aluminum alloy during brazing. The reaction makes the appearance of the oil cooler dark and the quality of the brazing seam poor. The interior of the air cooled oil cooler is relatively isolated from the outside, the $KAlF_4$ flux can hardly contact and effect the brazing process of the interior of the oil cooler. Consequently, the brazing seam of the interior of the oil cooler is very good, with bright color.

46.5 The Conclusions

Fluxless CAB brazing of air cooled oil cooler with fluxless brazing alloy was carried out, the conclusions are as follows:

- (1) The appearance of the oil cooler turns to dark after brazing, and the brazing seam fillets size of the middle plates of the outside of the oil cooler are very small. Hardly can it be seen by naked eyes.
- (2) The microstructure of the brazing seams of the oil cooler are analyzed, The brazing fillets of the interior of the oil cooler are very big, the brazing fillets near the outside of the oil cooler are very small. The molten brazing filler metal flows from the surface of the outside of the oil cooler to the interior during brazing.

- (3) By SEM analyzing, the Al–Si eutectic structure can be seen on the surface of the interior of the product, but it cannot be seen at the outside of the oil cooler. By magnifying 5000×, a layer covered on the surface of the middle plates of the outside of the oil cooler can be found, with white needle-like substance embedded in it.
- (4) The surface of the outside of the oil cooler contains high F, K, Mg content, but the interior contains little F and Mg, with no K element contained. The existence of KAlF₄ flux takes effect on the oxide removing ability of the Mg element contained in the fluxless brazing alloy, and makes the brazing process failed.

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