Research on the physical properties and film removal mechanism of silver brazing flux by micro morphology analysis and X-Ray Diffraction

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Abstract. The effect of KHF₂ addition on silver brazing flux was studied in this paper. Results showed that the melting temperature of brazing flux would sustainably decrease with the increasing content of KHF₂. KF could not be completely replaced by KHF₂ because it could restrain excessive spreadability, which was resulted from KHF₂. F element in the flux replaced O element to form Fe₂F₅.

1. Introduction
Silver brazing alloys is a kind of common brazing filler metals. Silver Brazing flux is usually required when use brazing alloys in the air [1]. Although commonly used silver flux mainly includes QJ102 flux, QJ308 flux and so on [2], FB104 flux is the special flux for furnace brazing. It contains 50wt% Na₂B₄O₇, 35wt% H₃BO₃ and 15wt% KF. Its melting temperature ranges from 650℃ to 850℃ [3]. According to Chenggen Wu’s research, the existence of Na element results in the generation of yellow flame and foaming phenomenon in brazing process [4]. Na₂B₄O₇ is usually replaced by K₂B₄O₇. However, KF shows strong hygroscopic, resulting in difficulty in storage for FB104 brazing flux [5]. Besides, the use of FB104 flux is limited because it could not be used at low temperature. Hence it is of great significance to research and modify the performance of FB104 flux. Many scholars have studied the modification of silver flux from the aspects of composition ratio and configuration process [6-9]. There are few researches on the reaction mechanism of silver brazing flux. In this paper, the effect of KHF₂ on properties of FB104 silver brazing flux was investigated. The film removal mechanism was studied.

2. Experimental

2.1. Materials
A Q235 steel matrix sample was used in the melting experiment with 40mm×40mm×2mm dimensions. The chemical composition of Q235 steel was listed in Table 1.

| Material | C      | Mn     | P      | S      | Si     | Fe         |
|----------|--------|--------|--------|--------|--------|------------|
| Q235     | 0.14-0.22 | 0.30-0.65 | 0.045  | ≤0.05  | 0.30   | balanced   |
K$_2$B$_4$O$_7$, H$_3$BO$_3$, KF and KHF$_2$ flux components were prepared for flux configuration. Silver brazing flux were made by mechanical mixing method at room temperature. The ratio of K$_2$B$_4$O$_7$ and H$_3$BO$_3$ in the new flux remains unchanged. KHF$_2$ partially or completely replaced KF on basis of FB104 flux. The detail was shown in Table 2. Further modification was on the foundation of No.1 to No.4 flux. The detail was shown in Table 3.

### Table 2. The chemical composition of silver brazing flux.

| Numbers of new flux | K$_2$B$_4$O$_7$ | H$_3$BO$_3$ | KF | KHF$_2$ |
|---------------------|---------------|-------------|----|---------|
| 1                   | 50            | 35          | 15 | 0       |
| 2                   | 50            | 35          | 10 | 5       |
| 3                   | 50            | 35          | 5  | 10      |
| 4                   | 50            | 35          | 0  | 15      |

### Table 3. The chemical composition of modified silver brazing flux.

| Numbers of new flux | K$_2$B$_4$O$_7$ | H$_3$BO$_3$ | KF | KHF$_2$ |
|---------------------|---------------|-------------|----|---------|
| 5                   | 47.2          | 33.1        | 4.7| 15      |
| 6                   | 44.4          | 31.1        | 4.5| 20      |
| 7                   | 41.7          | 29.2        | 4.1| 25      |
| 8                   | 39            | 27.2        | 3.8| 30      |

2.2. Methods
A box-type resistance furnace (SX2-5-13C) was used for melting experiment. 0.2g flux was put on the Q235 steel plate and sent it to the furnace later. The melting time at different temperature was recorded.

Water absorption test of silver brazing flux was carried out in the atmosphere with room temperature (25°C) and normal humidity (80% RH). An Electronic balance (BSA124S) was used to record weight change after 3 days, 5 days and 7 days.

The scanning electron microscope (SEM, Quanta FEG 250) equipped with energy dispersive spectroscopy (EDS) was used to observe the microscopic morphology of the silver brazing flux and reaction products and determine the chemical composition. X-ray diffraction (XRD, Smart lab 9K) was used to analyze the silver brazing flux reaction mechanism.

3. Results and discussion

3.1. Water absorption and morphology analysis
The weight changes from No.1 to No.4 flux was shown in Table 4 and Fig.1. The weight absorption substantially dropped owing to the decrease of KF content from No.1 flux to No.4 flux. No.4 flux has the lowest water absorption. Fig.2 showed the micro morphology from No.1 to No.4 silver brazing flux before and after water absorption test. Obvious agglomeration occurred after water absorption for days. The addition of KHF$_2$ could inhibit the formation of agglomeration due to low water absorption.

### Table 4. Weight changes of silver brazing flux.

| Numbers | 0day/g | 3days/g | 5days/g | 7days/g | Water absorption(7days)/% |
|---------|--------|---------|---------|---------|--------------------------|
| 1       | 10.0025| 10.0941 | 10.1438 | 10.2651 | 2.6253                   |
| 2       | 10.0009| 10.0547 | 10.0961 | 10.1264 | 1.2549                   |
| 3       | 10.0016| 10.0397 | 10.0549 | 10.0740 | 0.7239                   |
| 4       | 10.0018| 10.0098 | 10.0137 | 10.0181 | 0.1626                   |
3.2. Melting characteristics and EDS results

Surface morphology of Q235 steel plate after film removal was shown in Fig. 3(a). The four kinds of flux performed well at film removing. Fig. 3(b) showed the melting time changes of these brazing fluxes at different testing temperature. It indicated that melting point reduced with the increasing content of KHF$_2$ from No.1 flux to No.4 flux. No.4 flux had the lowest melting temperature, which could reach to 610°C. However, No.4 flux could not provide the enough active time to guarantee successful brazing because of excessive spreadability as shown in Fig.4. The addition of KF could solve this problem because it can increase the melting point of brazing flux [3]. High melting point restrain spreadability of brazing flux. Therefore, KF could not be completely replaced by KHF$_2$. The overall performance of No. 3 flux is superior.
Figure 3. (a) Surface morphology of Q235 steel plate (b) relationship between melting time and melting temperature of No.1 to No.4 flux.

Figure 4. No. 4 flux at 700°C for 3min.
Further modification was based on the foundation of No.3 flux. Keep the mass ratio of $\text{K}_2\text{B}_4\text{O}_7$, $\text{H}_3\text{BO}_3$ and KF 10:7:3. The content of KHF$_2$ ranged from 15% to 30% when the total amount remained unchanged. The detail was mentioned in Table 3.

Fig. 5(a) showed the surface morphology of Q235 steel plate after film removal. The four kinds of flux performed well at film removing. Fig. 5(b) showed the melting time changes with different melting temperature form No.5 to No.8 silver brazing flux. Result showed that melting temperature further decreased with the increasing content of KHF$_2$. No.8 flux had the lowest melting temperature. It reduced to 530℃. Hence the addition of KHF$_2$ could decrease the melting temperature significantly.

EDS result of No.1 and No.7 silver brazing flux was shown in Fig.6. Result showed that the reaction products of the flux and the oxide film include B, F, O, K and Fe elements.

![Figure 5](image1)

**Figure 5.** (a) Surface morphology of Q235 steel plate (b) relationship between melting time and melting temperature of No.5 to No.8 flux.

![Figure 6](image2)

**Figure 6.** EDS results of silver brazing flux (a) FB104 flux (b) No.7 flux.
3.3. XRD results
Fig.7 showed the XRD results. There were Fe$_2$F$_5$ in the reaction product, revealing that F element replaced O element in the oxide. Crystal KF, KHF$_2$, K$_2$B$_4$O$_7$ and H$_3$BO$_3$ were not found in the XRD results. According to the reaction formula on *Handbook of Brazing and Soldering* [3], the reaction of FB104 flux and the KHF$_2$-adding silver brazing flux were as following formula.

\[ K_2B_4O_7 \rightarrow B_2O_3 + 2KBO_2 \]  
\[ 2H_3BO_3 \rightarrow B_2O_3 + 2H_2O \]  
\[ KF/KHF_2 + Fe_xO_y \rightarrow Fe_2F_5 \]  
\[ Fe_xO_y + B_2O_3 \rightarrow Fe_xO_y \cdot (B_2O_3)_n \]

Where 0<n<1; when x=1, y=1; when x=2, y=3; when x=3, y=4.

![Figure 7. XRD results of silver brazing flux (a) FB104 flux (b) No.7 flux.](image)

4. Conclusion
This paper focused on the effect of KHF$_2$ on the FB104 brazing flux. Results showed that KHF$_2$ addition could decreased the melting point of silver brazing flux and inhibit the formation of agglomeration due to the low melting temperature and water absorption, respectively. KF could not be completely replaced by KHF$_2$. Because brazing flux with overmuch KHF$_2$ content could not provide the enough active time to guarantee successful brazing because of excessive spreadability. F element in the flux replaced O element of iron oxides on the surface of steel plates to form Fe$_2$F$_5$. 
Acknowledgments

This work was financially supported by National Natural Science Foundation of China (U2004186) and Zhengzhou Major Technological Innovation Project (2019CXZX0060).

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