Properties and structure of composite solders for aluminum alloys

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Abstract. The paper deals with the issues of improving the performance of solders for soldering aluminum alloys. The activity of fluxes under the conditions of interaction with aluminum alloys is investigated. The technological mode of flux production has been developed, which increases the tensile strength and corrosion resistance of brazed structures of radio-electronic equipment made of aluminum alloys.

Keywords: fluxes, aluminum alloys, brazed joints, grain size, tensile strength.

1. Introduction
Brazed structures made of aluminum and its alloys are widely used in rocket and space, aviation, automotive, engineering, chemical, instrumentation and other industries [1-3].
The features of high-temperature soldering of aluminum alloy parts are determined by such factors as the presence of an oxide film on the metal surface, the narrow melting interval of most industrial aluminum alloys, the high heat capacity of aluminum [4, 5].
High chemical and thermodynamic resistance characterizes aluminum oxide film. The melting point of aluminum oxide $\alpha$-$\text{Al}_2\text{O}_3$ is 2045°C, the boiling point is 2980°C. The aluminum oxide Film is practically not reduced in the gaseous media used and does not evaporate when soldering in a vacuum. Since the melting point of the aluminum oxide film significantly exceeds the melting point of brazed aluminum alloys, chemically active reagents or so-called fluxes are used to remove it.
The main purpose of fluxes is to remove from the contact surfaces of the connected parts resistant aluminum oxides, which prevent wetting of the base metal with liquid solder and spreading. Fluxes should contribute to the reliable removal of the oxide layer from the surface of aluminum, protect the joints in the soldering process from re-oxidation, have a temperature of activity lower than the melting point of the solder, ensure wetting and uniform flow of solder into the gap [6, 7].
To improve the accuracy of electronic equipment and all aviation equipment, the question of improving their operational properties is acute [8-10]. In many cases, the latter depend on the characteristics of brazed joints of aluminum parts.
The purpose of the work is to develop a technology for obtaining flux for soldering parts of basic elements of electronic equipment made of aluminum alloys, which are subject to high strength requirements [11, 12].

2. Materials and methods of the experiment
The studies were carried out with fluxes of two compositions characterized by a different mechanism of chemical interaction with the oxide film of aluminum alloys: 1) composition No. 1 included potassium chlorides, lithium, sodium, zinc, potassium fluoride; 2) composition No. 2 included potassium chlorides, lithium, sodium, potassium fluorides and aluminum. Basic data on materials for the production of pilot batches of flux are given in Table 1, and the chemical composition of the fluxes-in Table 2.

| The component name | Composition 1 | Composition 2 |
|--------------------|---------------|---------------|
| Lithium chloride   | 22.55         | 32.40         |
Table 2. The chemical composition of fluxes, %

| The composition No. | The content of the reagents, mas. % |
|---------------------|------------------------------------|
| 1                   | 40,20% KCl + 22,55% LiCl + 16,20% NaCl + 9,00% KF + 5,70% ZnCl₂ |
| 2                   | 41,90% KCl + 32,40% LiCl + 16,20% NaCl + 5,13% KF + 4,37% AlF₃ |

Aluminum alloy of AD₃₁ brand and aluminum alloy of ASi₁₂ brand were used to make samples of soldered joints. The chemical composition and properties of the alloys are given in Tables 3-6.

Table 3. The chemical composition of aluminum alloy AD₃₁, %

| Al       | Fe     | Si     | Mn     | Cr     | Ti     | Cu     | Mg     | Zn     |
|----------|--------|--------|--------|--------|--------|--------|--------|--------|
| 97,65-99,35 | до 0,5 | до 0,1 | до 0,1 | до 0,15 | до 0,1 | до 0,45-0,9 | до 0,2 |

Table 4. Physical and mechanical properties of grade aluminum alloy AD₃₁

| The indicator                                      | The value at 20°C | The value at 100°C |
|----------------------------------------------------|-------------------|--------------------|
| The density, kg / m³                               | 2710              | -                  |
| The fusion temperature, °C                         | 620               | 620                |
| The Young's modulus, MPa                           | 0,71              | -                  |
| The coefficient of thermal expansion, 1 / deg      | -                 | 23,4               |
| The coefficient of thermal conductivity, (W / (m · deg)) | -             | 188               |
| The specific heat, [J / (kg · deg)]                | -                 | 921               |
| The specific electrical resistivity, Ohm · m       | 34,4              | -                  |
| The tensile strength, MPa                          | 127               | -                  |
| The yield strength, MPa                            | 69                | -                  |
| The elongation, %                                  | 13                | -                  |

Aluminum alloy ASi₁₂ according to GOST 1583 was used as solder for the production of samples of soldered joints.

Table 5. The chemical composition of aluminum alloy ASi₁₂, %

| Al | Si | Fe | Mn | Ti | Cu | Zn | Zr | Mg |
|----|----|----|----|----|----|----|----|----|
Table 6. Physical and mechanical properties of grade aluminum alloy ASi12

| The indicator                                 | The value at 20°C | The value at 20°C |
|-----------------------------------------------|-------------------|-------------------|
| The density, kg/m³                            | 2650              | -                 |
| The fusion temperature, °C                    | 577               | -                 |
| The Young's modulus, MPa                      | 0.7               | -                 |
| The coefficient of thermal expansion, l/deg   | -                 | 21.1              |
| The coefficient of thermal conductivity, (W/(m·deg)) | -              | 168               |
| The specific heat, [J/(kg·deg)]               | -                 | 838               |
| The specific electrical resistivity, Ohm·m    | 54.8              | -                 |
| The tensile strength, MPa                     | 147-157           | -                 |
| The yield strength, MPa                       | 2-3               | -                 |
| The elongation, %                             |                   |                   |

For tensile testing, flat samples of aluminum alloy AD31 by 3 mm thick both butt and lap type according to GOST 19249 were used.

Before soldering the samples were cleaned from burrs and etched in 10-15% NaOH solution for 5 min. The flux was applied to the joined surfaces in the form of a paste on isopropyl alcohol. Soldering was carried out in a special conductor to prevent the shift of workpieces in the heating process and provide a predetermined gap. After soldering the samples were cleaned of flux residues by washing in hot water and visually checked for the quality of soldering (uniformity and integrity of the fillet, absence of non-solder). In the lap joint and butt joint type, the width of the solder joint was 3.0 mm and 2.8 mm, respectively, and the thickness of the solder joint in both cases was 0.1 mm.

3. Experimental results and discussion

Tests to determine the tensile strength of brazed joints of aluminum alloys was performed on testing machine Tiratest 2300 with loading rate 3 mm/min during the tests was determined by the highest destructive load ($P_{max}$) under tension, and after the test were visually estimated the location and nature of fracture of brazed joints of aluminum alloys. The results are shown in Figure 1.
Figure 1. The older joint sample after test (a) and the tensile strain diagram of solder joint sample (b)

The analysis of the microstructure of the weld and the fillet part of solder joints was performed using experimental batches of fluxes of composition No. 1 and composition No. 2. The analysis showed that the structure of all solder joints based on aluminum alloys AD31 and ASi12 consists of grains of primary solid solution and eutectic component (Figure 2 a, b).
Figure 2. The microstructure of the weld and the fillet part of the brazed joints aluminium alloys AD31 and ASi12, made with the use of experimental batches of fluxes composition No. 1 (a) and composition No. 2 (b).

The structure of solder joints of samples made with the use of flux composition No. 1 is characterized by a somewhat high content of defects (pores). The basis of the mechanism of work on the removal of films from aluminium oxide are the processes of chemical reactions of reduction with the formation of gaseous aluminium chloride. This contributes to the mechanical destruction and exfoliation of oxide films, but increases the content of pores [13, 14]. The structure of solder joints of samples made with the use of flux composition No. 2 is characterized by the content of a small amount of eutectic component and pores, as well as the formation of small grains of isometric shape. This is due to the favorable influence of eutectic melt based on aluminium and potassium fluorides, effectively dissolving aluminium oxide films [15-17]. The results of tests of samples of solder joints with the assessment of properties of solder joints are given in Table 7.

Table 7. The test results of solder joints

| The samples No. * | The composition No. | The area of the solder joint, mm² | The maximum breaking load, kN | The tensile strength, MPa |
|-------------------|---------------------|---------------------------------|-----------------------------|----------------------|
| PN-1-1            | 1                   | 75                              | 10.72 ± 0.88                | 142.95 ± 11.74       |
| Sample Type | Tensile Strength (MPa) |
|-------------|------------------------|
| PN-1-2      | 10.81 ± 0.71           |
| PN-2-1      | 8.69 ± 0.31            |
| PN-2-2      | 8.98 ± 0.43            |
| PV-1-2      | 144.12 ± 9.53          |
| PV-2-1      | 124.40 ± 4.03          |
| PV-2-2      | 128.25 ± 6.18          |

*where PN-1 - samples lap joint type; PV-2 - samples butt joint type*

The test results showed that for samples of solder joints made using flux composition No. 1 tensile strength for samples of butt type is from 121.20 MPa to 128.10 MPa, and for samples of overlap type - from 128.90 MPa to 149.92 MPa. The structure of the solder joint seam in some cases is characterized by the presence of defects, and the destruction of samples occurs on the solder joint.

For samples of solder joints made using flux composition No. 2 tensile strength for samples of butt type is from 123.36 MPa to 136.23 MPa, and for samples of overlap type - from 135.50 MPa to 152.65 MPa. The structure of the solder joint seam is characterized by the absence of defects, the destruction of solder joints occurs through the base metal.

**Conclusions**

1. Tensile strength of butt and lap samples of solder joints made with the use of experimental batches of fluxes of compositions No. 1 and No. 2 exceeds 120 MPa, which will ensure increased reliability of solder joints.
2. Samples of solder joints made using flux composition No. 2 are characterized by higher values of tensile strength due to the less content of eutectic component and pores, as well as the formation of smaller grains in the structure of solder joints.
3. By results of tests it is established that experimental compositions of fluxes No. 1 and No. 2 can be used at development of technological processes on production of soldered basic elements of the radioelectronic equipment from aluminum alloys to which requirements of the increased durability are imposed.

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