Study on Manual Tin Welding Technology of Platinum Wire-Copper Wire

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Abstract. Taking the manual welding of platinum wire and copper wire for spacecraft as the research object, the principle of manual welding of platinum wire and copper wire and the mechanism affecting the welding quality are analysed and studied, and the optimal technological parameters of manual welding of platinum wire and copper wire are optimized through the verification of manual welding process test.

1. Introduction
The solder joints of spacecraft devices are required to have good reliability and stability because of their bad working environment. The purpose of this study is to find out the optimal welding parameters through theoretical analysis and experimental verification. In the welding process, there are two kinds of welding, one is the hard welding which is connected by the local melting of the solder at high temperature, and the other is the soft welding which uses the low melting point metal as the medium to connect the solder. The common point is that the external temperature is used to complete the welding. The welding process of electronic products is based on tin alloy, which melts the tin alloy to form an effective connection between the two conductors with certain mechanical strength and conductivity. It belongs to the soft welding in the welding process. Manual tin welding has become one of the most widely used methods in welding of electronic products because of its flexible operation, simple equipment, low cost and wide application range.

The specifications of solders and solders are stipulated in the national standard GB/T 2423.28-2005 Environmental Test for Electrical and Electronic Products Part 2: Test Method Test T: Tin Soldering. The national standard GB/T 5095.6-1997 "Basic Test Rules and Measurement Methods of Electromechanical Components for Electronic Equipment Part 6: Climate Test and Tin Welding Test" stipulates the wetting test of solder and its detection method. National Standard GB/T 2423.32-2008 "Environmental Test for Electrical and Electronic Products Part 2: Test Method Ta: Weldability by Wetting Weighing Method" stipulates the wettability of welded parts and the devices for measuring wettability. The above standards do not specify the welding temperature.

It is generally believed that the factors affecting the quality of manual tin welding are: whether there is proper pre-treatment before welding; selection of flux, solder and soldering iron; selection of welding temperature; selection of welding speed. At present, the selection of welding temperature and speed is based on experience, and there is no reliable theoretical basis and data support.
Commonly used inspection methods for solder joints include visual inspection, electrical inspection, X-ray transmission inspection, mechanical damage inspection, microstructural examination, real load inspection, etc. Visual inspection is the most widely used non-destructive inspection method, which can inspect single solder joint defects, even abnormal lines and deterioration of components at the same time. However, internal defects such as voids cannot be found, so it is difficult to evaluate quantitatively. Electrical inspection is that welding products are electrified under loading conditions to check whether they meet the required specifications. It can effectively detect micro cracks and bridges that cannot be found by visual inspection. All kinds of electrical measuring instruments are used for inspection. X-ray transmission inspection, i.e. X-ray irradiation at the welding site, has become a representative non-destructive inspection method based on X-ray examination of internal defects. X-ray transmission inspection is effective for parts with large welding area. Mechanical damage inspection is a typical destructive inspection, which is to inspect the defects from its strength and fracture surface. From the tensile strength, shear strength, fatigue strength, vibration strength and so on to check, if the results are smaller than the standard, it shows that the solder joint is defective. In addition, fracture surfaces can be observed to detect voids and poor wettability. Microscopic examination is an effective method to cut and grind the weld, and to observe theinterface of the weld by microscopy. It is also an effective method to observe the corrosion of solder, the formation of alloy layer and micro-cracks. Real load inspection is to load every welded part under practical conditions to check its action status, including vibration inspection, impact inspection, hot and cold inspection, acceleration inspection, pressure inspection and so on. According to practical conditions, they are combined for practical inspection.

The commonly used solder is Sn-Pb binary eutectic alloy containing 37% Pb. Its phase diagram is shown in Figure 1. Sn-Pb eutectic structure is formed when solder is heated to liquid temperature and cooled. Both heating temperature and cooling rate will affect the size and morphology of eutectic structure, thus affecting the conductivity and strength of solder joints.

![Figure 1. Sn-Pb binary eutectic phase diagram.](image)

Resistance and mechanical properties are important performance parameters for joints. Low resistivity and high bonding strength are important criteria for high quality solder joints. The conductivity of metals is not only related to the properties of metals themselves, but also affected by grain boundaries. The existence of impurities and defects in grain boundaries will reduce the conductivity of materials.

Quantum mechanics proves that when an electron wave passes through an ideal complete crystal at absolute zero (OK), it will not be scattered without hindering its propagation, and the resistance will be zero. In fact, there are impurities and defects in the metal. When the temperature is not OK, the
Ionic vibration (thermal vibration) caused by temperature, as well as the impurity atoms, dislocations and point defects in the crystal will destroy the periodicity of the crystal lattice. The scattering of electron waves in these places will produce additional resistance and reduce the conductivity. Therefore, the total resistance of metals includes the resistance caused by basic resistance (temperature-dependent) and solute (impurity) concentration (temperature-independent), i.e. Matthiessen Rule, expressed in formula 1:

$$p = p_t + p_0$$  \hspace{1cm} (1)

In the formula, $p_t$ is the basic resistance of metal related to temperature, and $p_0$ is the residual resistance independent of temperature depending on chemical and physical defects. Chemical defects are impurity atoms and alloying element atoms added artificially; physical defects refer to vacancies, interstitial atoms, dislocations, etc. If the metal material is an ideal crystal without defects, the residual resistance $p_0$ is zero, so that the $p_t$ can be understood as the resistivity of the ideal crystal.

From Matthiessen Rule, it can be seen that the resistivity of metals depends on $p_t$ at high temperature and $p_0$ at low temperature.

The resistivity of metals increases with the increase of temperature. Although the temperature has little effect on the effective number of electrons and the average electron velocity, the lattice vibration increases with the increase of temperature, and the number of atoms deviating from the equilibrium position increases instantaneously. The free path of electron motion decreases, and the scattering probability increases, which leads to the increase of resistivity.

The lattice distortion and crystal defects increase, especially the increase of vacancy concentration, which results in the uneven electric field of the lattice and intensifies the scattering of electrons, thus increasing the resistivity of the material. Quantitative data of the effect of crystal defects on the resistivity of some typical metals have been obtained through a large number of experiments, as shown in Table 1.

### Table 1. Effects of various crystal defects on resistivity of some metals.

| Defect type      | Al  | Cu  | Ag  | Au  |
|------------------|-----|-----|-----|-----|
| vacancy          | 2.2 | 1.6 | 1.3±0.7 | 1.5±0.3 |
| Interstitial atoms | 4.0 | 2.5 |       |     |
| dislocation      | 10.0| 1.0 |     |     |
| grain boundary   | 13.5| 31.2| 35.0 |     |

According to the research, the conductivity of pure copper is exponentially related to the grain size. The smaller the grain size, the larger the resistivity. In addition to the effects of temperature and defects, alloying elements and phase structure also affect the electrical conductivity of materials.

The essence of manual welding is to solidify the solder again after melting. The solidification process of metals depends on the following two conditions: thermodynamic conditions, i.e. the possibility of phase transformation, and dynamic conditions, i.e. whether phase transformation can be carried out at a useful rate.

The solidification process of metals can be divided into two processes: nucleation and growth. When liquid metals have solidification conditions, no matter how fast the solidification process proceeds, it always takes a certain time to complete the transformation of this state that is, there must be a phase of coexistence of liquid phase and solid phase. At the beginning of the solidification process, a very small solid core, i.e. nucleation, always appears in some part of the liquid phase. Then the nucleus grows up gradually, and finally complete all the transformation, which is the process of crystal growth. In the process of crystal growth, new nuclei will be formed. The solidification process is the sum of nucleation process and crystal growth process. The dynamic condition of the solidification process is whether there are enough embryos in the supercooled liquid phase to reach the
critical size, so that the solidification process can proceed at a useful speed. When the liquid supercooling is high, a large number of nuclei will be formed at the same time, which makes the grain of solidified structure finer.

2. Process test design

2.1. Test purpose
Manual soldering process test is used to determine the optimal process parameters of manual soldering between platinum wire (0.3mm in middle) and wire (FYl-219 *0.12), including heating temperature of soldering iron, cooling time of power cut and soldering time, in order to ensure the reliable connection between platinum wire and wire.

2.2. Test object and equipment
The appearance, metallographic structure and tensile strength of solder joints at different temperatures (280 - 330 C) were observed and measured.
- Soldering Iron: ERSA AnalyOG60A
- Soldering Iron Thermometer: White Light 101 (FG-101)
- Video Microscope: KH-3000
- Scanning Electron Microscope: CamScan 3400
- Tensile testing machine; Instron 5565
- microhardness tester: HXZ-1000

2.3. Test analysis method

2.3.1. Visual inspection. The welding quality was evaluated by naked eye, magnifying glass and stereo microscope. Examination contents include: whether the surface of solder joint is smooth and bright, whether there are pinholes or non-crystalline state; wetting condition of solder to welding surface: insufficient or excessive solder; whether there are cracks, fracture or separation between solder and connector. Appearance examination can be carried out by means of magnifying glass and stereomicroscope.

2.3.2. Metallographic examination. The welded parts are made into metallographic samples, each sample is polished and observed at least three depth sections. By making metallographic specimens at solder joints and observing them under optical microscope, we can analyse whether the solder structure is uniform, whether there is pore or not, and whether the interface is continuous.

2.3.3. Scanning Electron Microscope and Energy Spectrum Fractionation. The metallographic specimens were analysed by scanning electron microscopy and energy dispersive spectrometry, and the microscopic characteristics and phase composition of the solder joints were analysed. By means of SEM and ED’s analysis of metallographic specimens, the microstructure and phase composition of solder joints can be analysed on a more microscopic scale. The mode, cause and mechanism of fracture can be further analysed by means of SEM and ED’s analysis of fracture surface in static tension test, which can provide reference for optimizing welding process.

2.3.4. Microhardness test. The hardness and strength of solder and platinum wires can be effectively evaluated by microhardness test of metallographic specimens.

2.3.5. Mechanical Properties Test. The static tension test method can be used to evaluate the bonding strength of solder and welding interface effectively.
3. Test results and analysis of technology

3.1. Visual inspection
The appearance of the specimens welded between 280 and 330°C at fast (2 ~ 3 seconds) and slow (4 ~ 5 seconds) speeds was examined and photographed under a video microscope. It was found that the surface of solder joint was smooth and bright, without pinholes or amorphous state; the wetting condition of solder on the welded surface was good; the solder shortage existed in individual weldments (rapid at 290 ~ 310°C); There was no crack, fracture or separation between solder and connector. The effect of welding parameters on the appearance of solder joints is not obvious.

3.2. Study on the Effect of Welding Parameters on Microstructure of Solder Joints
The microstructure of solder joints is eutectic structure of tin and lead phases. According to the experimental results, quantitative metallographic analysis of solder joints under different welding processes is carried out. The results are shown in Figure 2.

![Figure 2. Temperature-Bulk Lead Ratio Curve of Platinum Wire-Copper Wire Hand Welding.](image1)

As can be seen from Figure 2, the overall trend is that the proportion of bulk lead phase increases with the increase of temperature, and the proportion of lead in slow welding fluctuates relatively small. In theory, the increase of the proportion of large lead means that the proportion of small lead decreases, and the phase boundary between lead and tin phase decreases relatively, and the resistivity decreases.

3.3. Study on the influence of welding parameters on solder hardness
The microhardness of the metallographic specimens of solder joints is tested, and the results are shown in Figure 3. It can be seen from the figure that the solder hardness at 280°C and 330°C is lower than that at adjacent temperatures, whether in fast or slow soldering.

![Figure 3. Temperature-Tin Hardness Curve of Platinum Wire-Copper Wire Hand Welding.](image2)
3.4. Study on the Law of Welding Parameters Influencing the Strength of Welded Parts.

The processing process of platinum wire determines its work hardening characteristics, annealing occurs at a certain heating temperature, and the hardness of platinum wire decreases. There is a turning point of annealing temperature for platinum wire at about 300°C. When annealing temperature is higher than this, the hardness of platinum wire drops sharply.

The microhardness of platinum wire at solder joints was tested under different welding parameters. It can be seen that the hardness of platinum wire decreases slowly before 330°C, but decreases greatly at 330°C, which indicates that 330°C is the turning point of annealing temperature for platinum wire used in this experiment.

Static tension tests were carried out on the welded specimens at 280, 320 and 330°C, respectively. The results are shown in Table 2. For industrial pure platinum (99.95% Pt), after 50% cold working deformation, its tensile strength is 205-240 MPa. Although three of the four samples are broken near the solder joint, which may be related to the influence of welding temperature, the tensile strength of the samples is generally sufficient.

| Welding Temperature of Sample | Tensile Strength | Fracture Location            |
|-------------------------------|-----------------|------------------------------|
| 280                           | 351.31          | Near solder joint            |
| 320                           | 319.74          | Near solder joint            |
| 330                           | 335.42          | Near solder joint            |
| 330                           | 332.34          | Keep away from solder joints |

4. Selection and analysis of welding parameters

4.1. Choice Basis

Conductivity and strength are the main performance indicators for evaluating welding joints. Because conductivity cannot be measured directly, the relative conductivity can be indirectly reflected by the morphology of metallographic structure.

4.2. Selection of metallographic structure

The conductive principle of metal is the directional movement of free electrons. For the same metal, the main factor affecting its conductivity is the number of grain boundaries, because the existence of grain boundaries will hinder the movement of free electrons. For the structure with large lead phases, the barrier to free electrons is relatively small due to its relatively small grain boundaries, so its conductivity is also better.

For the cooling and solidification process of manual welding solder, the main cooling methods are heat conduction and air convection of platinum wire and copper wire. When the welding temperature is lower, the corresponding temperature of platinum wire and copper wire is also lower, the solder will be cooled to below the melting point at a faster speed, and the undercooling degree is larger, so the grain size will be relatively small; when the welding speed is faster, the solder will also be cooled to below the melting point at a faster speed, and the undercooling degree is larger, so the grain size will be relatively small. On the contrary, when the welding temperature is higher or the welding speed is slower, the undercooling degree is smaller and the grain size is larger.

From the results of the experiment in Figure 2, it can be seen that the proportion of bulk lead phase increases with the increase of temperature, and the proportion of lead in slow welding fluctuates relatively small. Therefore, the three better welding parameters are 320 slow welding, 330 fast welding and 330 slow welding, respectively.
4.3. Selection of mechanical properties
As can be seen from Figure 3, the solder hardness at 280–330 °C is lower than that at adjacent temperatures, whether in fast or slow soldering. Before 330 °C, the hardness of platinum wire decreased slowly, but at 330 (?) C, the hardness of platinum wire decreased dramatically, indicating that 330 (?) °C is the turning point of annealing temperature for platinum wire used in this experiment. Therefore, welding at 330 C should be avoided.

5. Concluding remarks
Through theoretical analysis and evaluation of the joint performance of manual welding test of platinum wire and copper wire with different process parameters, it is concluded that the optimum parameters of manual welding of platinum wire and copper wire should be slow welding at 320 C, which provides technical basis for the selection of parameters of manual welding of platinum wire and copper wire in engineering practice.

6. References
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