

Solderability assessment of galvanic coatings in electronics

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ABSTRACT

The problem of providing high-quality soldered joints during the assembly and installation of electronic products draws attention to the use of effective methods for controlling the solderability of electronic components and functional coatings of parts. The solderability of electroplated coatings used in electronics was studied by two methods: evaluating the spreading of a dosed drop of solder and the wetting force by molten solder. The criteria for evaluating the solderability of coatings are systematized and refined.

KEYWORDS: solderability, galvanic coatings, wettability, solder drop height.

1. INTRODUCTION

In the production of modern electronics products, soldering processes occupy a significant part of the complexity of assembly and installation (more than 30%). More stringent requirements are imposed on the quality of products, since the reliability and performance of electronic systems depend on their quality. Since there is a printed circuit board in every electronic product, special attention is paid to the quality of their assembly and installation, and in particular to the quality of soldered joints [1]. To improve the quality of soldered joints and reduce their transient resistance, as well as to increase the soldering speed, functional coatings are applied to the terminals of the elements, switching devices, and the conductors of the printed circuit boards. Ensuring the above requirements is impossible without the development of highly efficient, productive control methods,

a special place among which, due to the wide distribution in the electronic of electroplated coatings, is occupied by methods for controlling their solderability. The quality of soldered joints largely depends on the coating properties of parts, electronic components and their solderability.

Solderability is the ability of a material to be wetted by molten solder and form a high-quality solder joint with it. Solderability is determined by the physicochemical nature of the materials and solder, the method and soldering regimes, fluxing media, the conditions for the preparation of soldered surfaces, etc. [2]. For the formation of a solder joint, it is necessary and sufficient to wet the metal surface with a solder melt, which determines the possibility of further formation of chemical bonds between them. Soldering should ensure the formation of tight joints and the required assembly strength at various operating temperatures. To perform these functions, the molten solder must wet the joined surfaces to penetrate into all the gaps of the joint, which makes it possible to determine its wetting ability. Solder must spread over the surface of metals, which allows to obtain information about the characteristics of solders depending on the chemical and physical nature of the surfaces to be joined, to establish the effectiveness of both systems of solders and fluxes, and the time of temperature cycles during soldering operations.

The solderability of component leads is difficult to assess visually; moreover, experience shows that coatings lose their solderability during storage. The gradual diffusion of copper into the tin coating or solder forms intermetallic compounds,

which, increasing on the brazed surfaces, cause the absence of wetting. The solderability of most galvanic coatings during aging decreases as a result of the formation of sulfide and oxide films under the influence of the atmosphere and diffusion of the coating metal into the base metal, which leads to a decrease in the coating thickness [3]. Therefore, it is necessary to check the solderability of such surfaces after storage in order to ensure high reliability and yield of products during soldering operations. The methods should provide the shortest control time, high reliability, automation control and analysis of results.

2. MATERIALS AND METHODS

2.1. Solderability testing methods

To assess the solderability, various test methods have been proposed, which can be divided into the following types: capillary penetration of solder into gaps, spreading of solder, immersion in solder, and wetting time. A critical assessment of various test methods allows for the correct selection of materials during soldering to obtain high reliability of the joints and to evaluate the optimal production data for soldering operations (Table 1) [4].

Capillary penetration tests are used to evaluate the effects of joint clearance, flux activity, or solder composition. A capillary space is created between two flat metal sheets. The joined surfaces of the sheets are fluxed, heated and immersed in a bath

with molten solder for a certain time. After that, the sheets are removed, cooled, and the capillary rise of the solder is measured. Abnormal results may occur due to oxidation of metal surfaces or changes in flux activity during preheating. Despite these anomalies, for the qualitative control of electrolytically tin-plated boards, the board samples are bent to form a capillary space. The test samples are fluxed at ordinary temperature and then vertically immersed in the bath for 1 min. After removing and cooling the sample, the bent edge is cut off. The sample is straightened, and the rise height of the solder is measured. The sensitivity of such a qualitative test is low, since it only demonstrates the difference in the capillary rise of solder from “good” to “bad” in the range of 0.2-0.4 cm with a full rise of 3 cm.

Measurement of the capillary rise of solders can be performed using metal pipes, bending wires and using internal confined spaces. In the case of bent wires, it was shown that stretching the wires when immersed in molten solder causes an uncontrolled change in the size of the capillary gaps. It should be noted that in all capillary lift tests using tin-lead alloys, the rise height of the solder depends largely on the presence of eutectic in the alloy of the solder, and the higher the percentage of eutectic, the higher the capillary rise.

In solder spreading test methods, a certain volume of solder and flux is applied to the test samples and the samples are then heated to a predetermined temperature using electrical resistive heating or

Table 1. Application of solderability testing methods.

Materials and components tested	Testing methods			
	Capillary penetration	Spreading	Immersion	Wetting time
Solders	■	■	■	■
Fluxing agents	■	■	■	■
Compound materials	■	■	■	■
Coatings	□	■	■	■
PCB conductors			■	■
Metallized holes	■		□	■
Component leads		□	■	■

■ - high reliability of the results; □ - low reliability of the results.

hot plates. Some immerse the samples on the surface of liquid solder or flux in a bath or use heat in an oven. However, such heating is not recommended due to the fact that the heating time is long, and without a protective or non-oxidizing atmosphere, the surface of the samples can be oxidized to such an extent that it affects the result of the experiment; in addition, prolonged heating does not reflect the real conditions of most soldering operations [5].

When samples are heated, the solder melts and spreads over the surface. The amount of spreading depends on the type of flux, the base metal and the composition of the solder. The volume of flux and solder is controlled by the use of a fluxed solder of a certain diameter and core size. In other cases, solder blanks or rings are stamped from a sheet of solder of known thickness and a metered amount of flux is applied to the sample with a graduated pipette.

After the solder spreads, the sample cools and the area can be measured either with a planimeter or the spot is photographed and enlarged to facilitate the measurement and increase the reliability of the measurements. Often the spreading area is projected onto the microscope screen and standard sheets of graph paper are used to determine it. If the spreading area and the solder volume are known, then the value of the theoretical contact angle of the solder drop on the surface is determined using the expression:

$$\theta = 7.12 (V / \sqrt{S^3}), \quad (1)$$

where θ is the angle in degrees, V is the solder volume, S is the spreading area.

The expression assumes that the solder volume is small and there is no gravitational effect which

allows us to quantify the solderability – small values of the angle indicate good solderability. Many researchers have made changes to the spreading area tests: by the maximum height of the molten solder after the experiment on the surface, one can judge the degree of solderability. However, this method is more suitable when the spreading area of the solder is approximately round, whereas the solder spreading pattern is often irregular due to the chemical and physical properties of the test surfaces. Spreading factor P proposed by *L. Pessel* [6] is calculated as:

$$P = 100 * (D - H) / D, \quad (2)$$

where D – diameter of the sphere having a volume equivalent to the solder used; H – height of the drop of solder.

In the absence of gravity, the drop of solder will have the shape of a sphere, where D will be equivalent to H and the spreading factor is 0. This indicates the absence of solderability. Percentages of solderability of coatings are given in Table 2.

Considering that under real conditions of soldering, the height of a “lying” drop of molten solder H_l is always less than the diameter of the hypothetical sphere of solder D , the following expression was proposed to calculate the spreading coefficient of solder K_h [7] (Figure 1):

$$K_h = \frac{H_l - H_d}{H_l} \quad (3)$$

where H_l is the height of the “lying” drop of molten solder, defined as

$$H_l = \frac{\sqrt{2\sigma(1 - \cos\theta)}}{\rho g} \quad (4)$$

where θ is the wetting angle of the surface with solder.

Table 2. Solderability assessment of coatings.

Spreading factor	Solderability	The wetting angle calculated by the spreading area
60	Very Bad	50°
60 - 70	Bad	50 - 34°
70 - 80	Satisfactory	34 - 12°
80 - 90	Good	12 - 3°
90	Great	3°

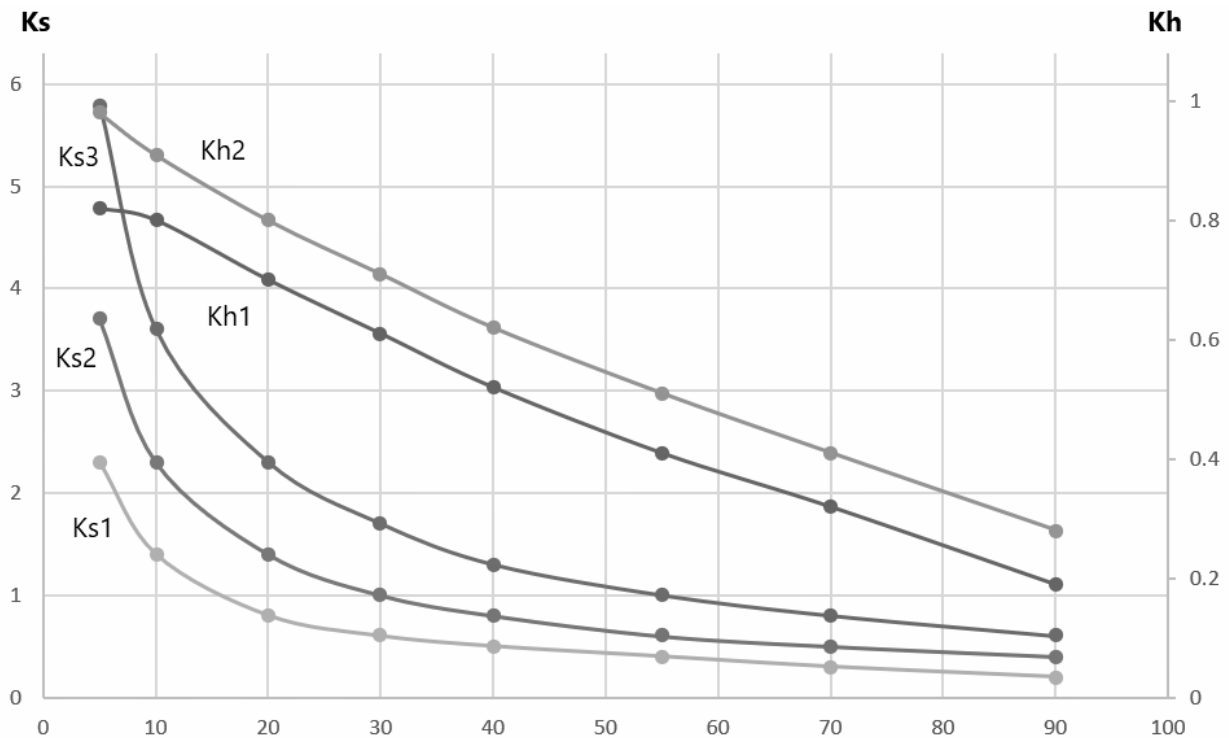


Figure 1. Dependence of the spreading coefficient along the height of the drop on the wetting angle and the initial height of the dose of solder ($Kh_1 - H_k = 3.82$ mm; $Kh_2 - H_k = 4.24$ mm) and on the wetting angle and mass of the dose of solder ($Ks_1 - 125$ mg; $Ks_2 - 250$ mg; $Ks_3 - 500$ mg).

In tests for the spreading of galvanic coatings with significant oxide films, it was shown that the solder was spreading under them, which made it difficult to control the area. It follows that spreading area tests are not suitable for aged thick coatings. To measure the height of the solder drop after spreading, the principle of non-contact measurement of the solder drop height using an inductive transducer (Figure 2) was proposed. Two inductive converters G1 and G2, two high-frequency generators Z, a frequency mixer UB, an integrator A1 and a recording device P were used for this purpose. The balanced circuit resulting from the operation of the generators allows to compensate for the frequency change caused by the heating of the inductive converters and increase the accuracy of measurements. The recorder measures the differential frequency obtained in the frequency mixer. A needle wetted by solder is rigidly fixed in the axial hole of the coil of the inductive transducer to center the drop of solder relative to the sensor [8]. The needle is installed on the test surface of sample; the length of the

needle must exceed the height of the solder droplets observed in the conditions of complete non-wettability of the surface.

The solder is melted by a resistive heating element H, on which the test samples are placed. Temperature control is carried out using an XK type thermocouple immersed in a dosed sample of solder on a witness specimen and connected to an electronic temperature gauge, which stabilizes the process temperature. Before starting the tests, a weighed sample of solder of a measured mass of 250 mg and a dosed volume of flux of 0.01 ml are applied in the center of the coated sample. The inductive transducer is placed on a flat solder blank so that the needle fixes the axial symmetry of the transducer and the solder blank. The stopwatch fixes the beginning and end of the spreading of the solder, and the height of the drop of solder is determined by the readings of the device.

Data processing is carried out using a PIC controller. To increase the accuracy of measurements, as well as to eliminate the temperature factor,

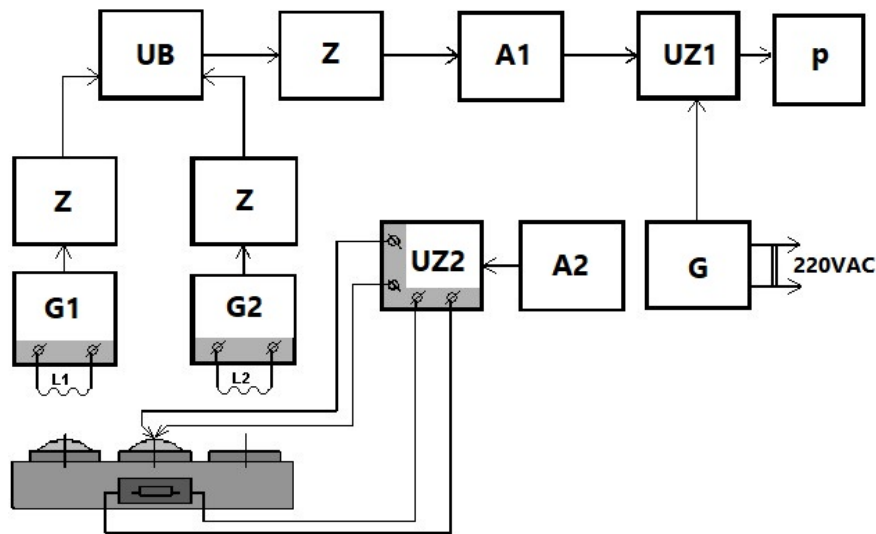


Figure 2. The diagram of the apparatus for evaluating the solderability of coatings by measurement solder drop height.

two identical inductors and a frequency meter on microcontroller were used in the converter of the developed device. In the microcontroller, the sixteen-digit timer-counter has an eight-bit pre-divider and a three-bit overflow counter, which totaled 27 bits. The performance of the microcontroller depends on the maximum measured signal frequency of 50 MHz.

The second interval is counted out using programmatically organized cycles, into which a dynamic indication of the readings is introduced. At the end of the count, the value of the measured frequency is obtained by polling the registers from the sixteen-digit timer-counter and three-digit overflow counter. To regulate and maintain the temperature of the heater at a predetermined level, an electronic power controller A2 is used. A feature of the device is the presence of a built-in temperature control unit UZ2, which made it possible to abandon the bulky external temperature meter and reduce the dimensions. The main parameters of the device are: resolution on the height of the drop of solder, which is determined by the sensitivity of the device and the stability of the reference frequency reference. The accuracy of determining the spreading coefficient is 1.5 times higher than by standard methods. When using the device, the end result is the height of the drop of solder. To move to the spreading coefficient, a special diagram is constructed.

Immersion methods are the earliest solderability tests, since the component leads are simply immersed first in the flux and then in the molten solder and the solderability is evaluated by the degree of coverage of their solder. As a part of the testing process, the samples are kept in the bath for 2 s, then removed from the bath to be cooled and purified with isopropyl alcohol. A significant spread of solder along the lead length (by 95%) indicates good solderability, and the formation of a solder ball with large contact angles indicates poor solderability. The remaining 5% of the non-wetted surface can be accounted for by pores, voids, provided that they are concentrated in more than one place. Evaluation of test results is sometimes difficult because coarse and even coatings are not clearly distinguished. The immersion method was developed for determining the solderability of printed circuit boards, layered structures, and other similar materials. Test samples are compared with standard ones, showing different degrees of wetting of the board sections with solder. The method is convenient for industry, since it allows you to determine the effectiveness of individual stages of processing boards and to identify unsatisfactory solderability, which can be corrected before assembly. A modification of the immersion method is the floating sample method for controlling the solderability of metallized holes. The boards are

fluxed and then kept floating on the surface of the bath for 5 sec. After removing the boards, the holes are inspected visually. Homogeneous wetting along the edges of the holes, as well as in length, indicates good solderability. However, a sophisticated electronic equipment requires increased reliability. In addition, production requirements suggest that several hundred connections must be made on the board by group soldering. The contact time of each of the compounds with the molten solder is about 2 s, and therefore the time and complete wetting of the surfaces of the components of the solder is very important for the formation of a reliable electrical connection.

Tests for the wetting time allow reproducing quite accurately the conditions of the operation of mass soldering and can be used to determine the quality of soldering of the outputs of elements or layers of boards or in other cases, printed circuits. These tests are proposed by *C. J. Thwaites*, chief metallurgist of the Tin Research Institute in the USA [9]. At present, an equipment has been developed for determining the minimum wetting time suitable for industry. It consists of a radial arm carrying a test sample over the surface of the solder bath and moving with a motor. A number of test samples are being kept in continuous contact with the solder bath. Visually, it is possible to determine the minimum wetting time, as well as the time from which wetting does not increase. After complete wetting is achieved, a further increase in the exposure time in the solder impairs the distribution of the solder. The rotation method is used to check the solderability of various surfaces and the optimal parameters of the soldering operation.

To test the solderability of the outputs of electronic components *J. A. ten Duis (Philips)* proposed a glob test method. A certain volume of solder (depending on the size of the wire being tested) is melted on a heated block, and the fluxed lead is lowered horizontally into the solder ball, splitting it into two. The time during which the solder flows around the wire and eventually closes the top of the wire is the wetting time. To detect a tendency to non-wetting, the wire should be removed from the solder ball, the excess solder must be wiped off and the test should be repeated. To simulate long-term storage, artificial aging is

performed for 16 hours at 155 °C in air. A dose of solder is placed on the heated table, which, when melted, forms a drop. A conductor is brought to the drop, which divides it into two parts. As the output heats up, the solder begins to wet and flow around it. At the moment of complete closure above the solder lead, it touches the probe and the countdown stops.

Wetting the surface with molten solder involves a gradual decrease in the contact angle as the surface tension forces change due to the interaction of the solder and the base metal. Therefore, by measuring surface tension, solderability can be estimated. For this purpose, an industrial equipment has been created and standards have been developed to quantify the solderability of surfaces and flux solders. The wetting balance test method (Figure 3) consists in directly measuring the wetting forces and the work of adhesion. The bath with solder moves upward with the help of an actuator and an eccentric, while the studied sample immersed in it is mounted on the sensor. The strain gauge type sensor converts the force into an electric signal, which is fed through the strain gauge amplifier to the recorder. Until the sample is heated, there is no wetting, the solder meniscus is bent down and only the solder buoyancy force F acts on the sample

$$F_a = S h g, \quad (5)$$

where S – sample area, h – immersion depth.

With full wetting at point B, the value of the wetting force is F_1 , and when the sample is torn off at point C, the wetting force reaches F_2 (Figure 4). The immersion rate of the samples is selected within 0.2-0.4 mm/s, the immersion time is 4-5 s, and the depth is 0.8-2.0 mm. A measure of solderability is the force F_1 and the time t_1 , during which it reaches this value. The cosine of the wetting angle is calculated using the formula:

$$\cos \Theta = (F_1 + F_a) / F_2. \quad (6)$$

This method is introduced into European and international standards (MIL – DIN – JIN – IPC) and is used to assess the solderability of a wide range of coatings, samples of printed circuit boards, chip components and the effectiveness of activated fluxes and lead-free solders [10].

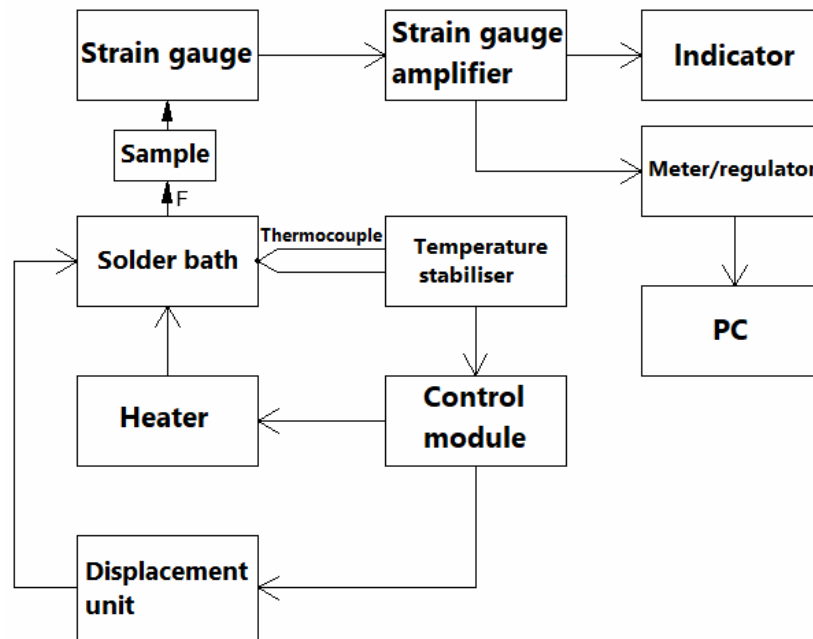


Figure 3. Structure diagram of a wetting balance test apparatus.

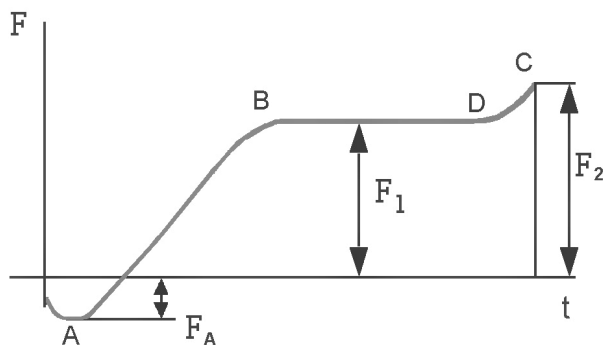


Figure 4. Meniscographic solderability control curve.

The wetting balance meniscograph provides the immersion depth of samples in the solder melt from 0.1 to 1.0 mm in 0.1 mm increments at a speed of 1 to 50 mm/s. The exposure time and observation is from 1 to 30 s. Good wettability corresponds to the surface tension of the solder from 350 to 450 mN. To determine the solderability of the component leads, a simpler meniscometric method is used, which consists in measuring the height of the meniscus of solder that has risen from the lead above the bath mirror under the influence of surface tension. The meniscus height above the solder mirror is measured using a

special optical head or binocular microscope. Meniscometers are manufactured by Metronelec (Switzerland) with a measurement range of 0-1.5 mm for meniscus lifting heights and an accuracy of ± 0.05 mm. Performance control - up to 30 pcs/hour.

3. RESULTS AND DISCUSSION

The values of the spreading coefficients of 61SnPb solder over the area and drop height are given in Table 3.

With prolonged exposure (more than 12 months), oxide films form on the tin coating, and solder spreads under the oxide films on some test surfaces. It follows that spreading area tests are not suitable for aged thick coatings. Figure 5 shows the samples used in the wettability tests of coatings of copper samples. At high wettability and correspondingly high spreading coefficient, which is key in evaluating solderability, a drop of solder is noticeably smeared on the surface of the sample (Figure 5a), while in cases of a lower spreading coefficient formed as a result of aging of the coating, tuberosity is observed within the volume of the solidified drop of solder (Figure 5b, c), which indicates a low solderability of the studied samples.

Table 3. Spreading coefficients and wetting angles of 61SnPb solder for galvanic coatings.

Coating type	Composition, %	Spreading coefficient,		Wetting angle, °
		by area	by height, %	
Tin	100 Sn	4.0 - 5.0	96 - 97	10 - 12
Golden	100 Au	3.0 - 3.5	94 - 95	18 - 20
Silver	100 Ag	1.5 - 2.0	87 - 89	40 - 45
Pd-Ni alloy	1,5 In, Pb	1.4 - 1.7	87 - 88	42 - 47
Sn-Bi alloy	3,0 Bi, Sn	1.4 - 1.6	86 - 88	48 - 50
Sn-Ni alloy	3,5 Ni, Sn	1.4 - 1.5	82 - 85	55 - 67
Sn-Pb alloy	50 Sn, Pb	1.2 - 1.3	80 - 83	64 - 75
Palladium	100 Pd	1.0 - 1.2	80 - 82	67 - 75
Copper	100 Cu	0.9 - 1.2	78 - 80	75 - 82
Nickel	100 Ni	1.0	70 - 75	>90

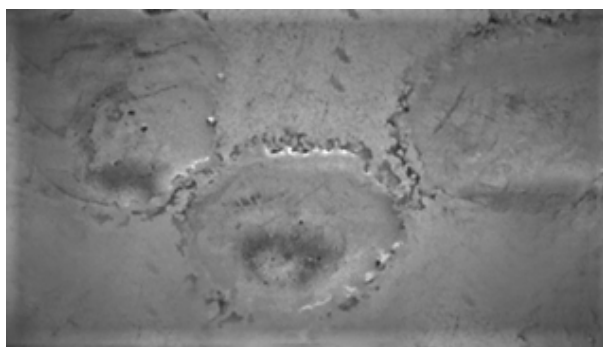
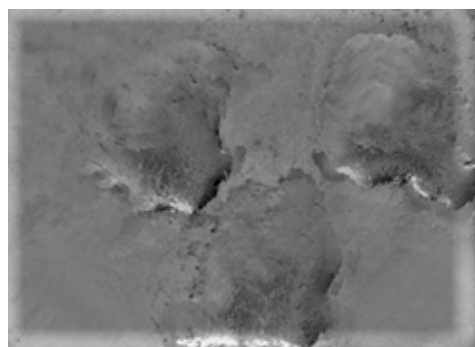
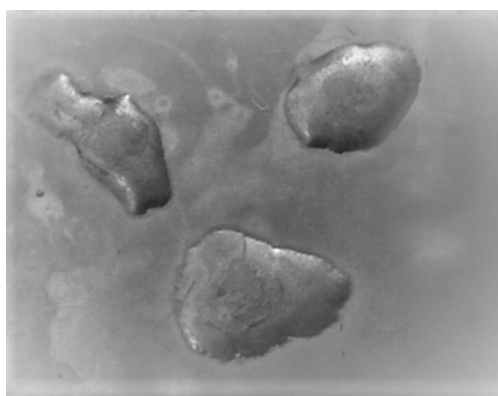
**a****b****c**

Figure 5. Solder interaction with a metal surface: **a** – high wetting, $K_h = 89\%$; **b** – high wetting, $K_h = 88.66\%$; **c** – low wetting, $K_h = 78.86\%$.

According to the results of measurements of spreading coefficient, it was found that tin, gold, silver coatings, as well as coatings with Sn-Ni, Pd-Ni alloys, have excellent solderability. Good results have been noted for coatings of Pd, Sn-Pb and Cu. In nickel alloys, alcohol rosin fluxes have low activity and form difficult-to-remove residues on soldered surfaces. To increase activity on copper and nickel surfaces, it is necessary to use activated ethylene glycol-based fluxes containing surfactants and activators in the form of oxalic acid and benzylamine derivative hydrochlorides. Such fluxes have 1.6-2.0 higher activity than the rosin, and its residues are easily removed from the surface of parts by washing in warm running water. For samples of coatings with Sn-Bi alloy

6 μm thick and 20 x 20 mm in size with an immersion depth of 1 mm, the values of forces F_a , F_1 and F_2 were determined and the contact angle of contact for the investigated solders was calculated at $F_2 = 0.72 \text{ N}$ (Table 4).

According to the European standard NF89400 Sn-Bi coating has excellent solderability, and for lead-free solders Sn3Cu and SAC305, the wetting angle is slightly higher, which corresponds to good solderability for rosin inactive fluxes. The wetting curves for freshly deposited and aged Sn-Bi plating are shown in Figure 6. As a result of aging of the coatings during their long-term storage, oxide films form on the surface, which increases the time and reduces the wetting force of solder.

Table 4. The values of the contact angle for solders.

Solder	Composition	$\theta, ^\circ$	$F_a, \cdot 10^{-2} \text{ H}$	$F_l, \text{ H}$
61SnPb	Sn61 Pb39	38	33.32	0.68
Sn3Cu	Sn97 Cu3	44	27.96	0.72
SAC305	Sn96,5Ag3Cu0,5	43	28.74	0.70

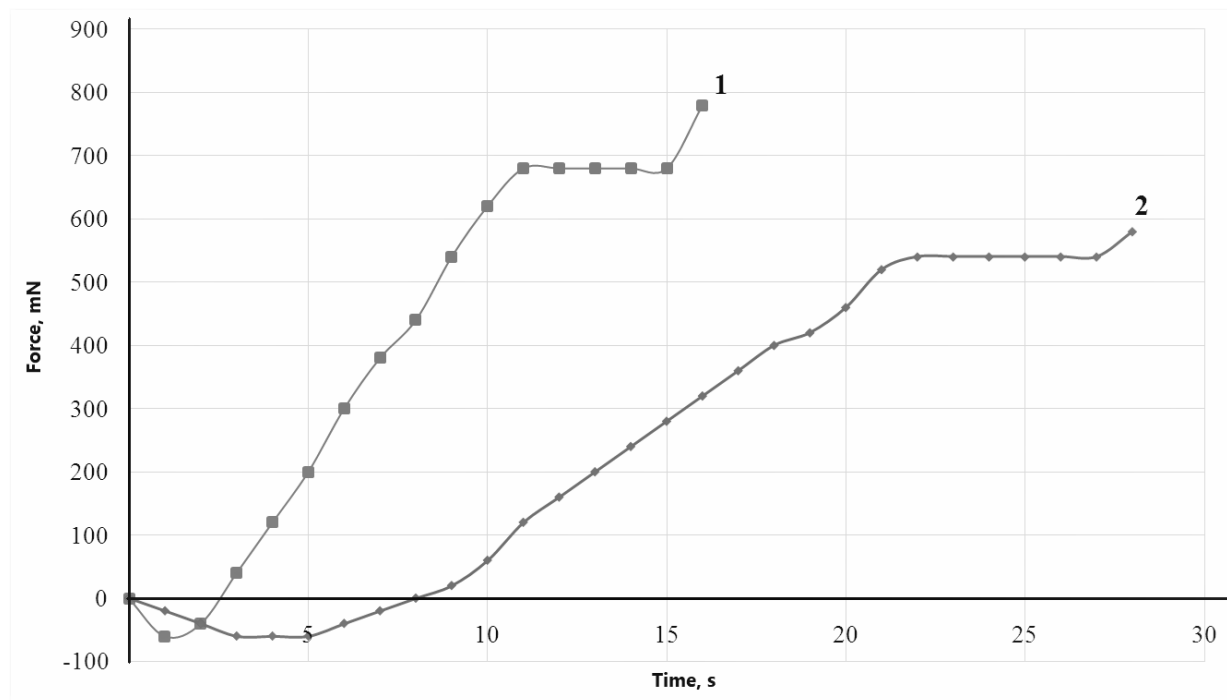


Figure 6. Wetting curves of Sn-Bi coatings: 1 – freshly precipitated, 2 – after aging.

To prevent the darkening of silver coatings during their operation, composite electrochemical coatings based on silver with the inclusion of ultrafine diamond particles (UDD) are used. Composite coatings in comparison with pure coatings have higher hardness and wear resistance, improved anti-corrosion properties and resistance to spark erosion. A study of the solderability of silver coatings was carried out by determining the spreading coefficient of a dosed preform of 61SnPb solder weighing 250 mg in the presence of alcohol rosin flux at a temperature of 220 ± 5 °C. The flux used contained 25% rosin and 75% isopropyl or ethyl alcohol by weight. The test was preceded by accelerated aging, which was carried out at 155 °C for 16 hours. After accelerated aging, the samples were kept in normal climatic conditions for at least 2 and no more than 24 hours.

The results of studies of the solderability of silver coatings showed that some deterioration in the solderability of silver – UDD coatings is observed only at 15 g/l of UDD in the electrolyte. By the value of the spreading coefficient of more than 80%, the solderability of composite silver coatings can be considered good.

4. CONCLUSION

The requirements for soldered joints in electronics are becoming more complex than before. Mass soldering of thousands of compounds in electronics requires reliable and cost-effective technologies, as well as advanced quality control methods. Solderability test methods allow you to objectively and accurately measure the ability of components and functional coatings to solder at the optimum time and a given temperature for the formation of compounds.

Of most methods for printed circuit boards, the rotational immersion method is convenient for evaluating solder – flux – metal systems and the minimum wetting time. To assess the solderability of a wide range of coatings, samples of printed circuit boards, chip components, the effectiveness of activated fluxes and lead-free solders, the wetting balance method is used. These methods can be successfully applied in industry and

integrated into production lines, which can significantly reduce rejects after soldering.

CONFLICT OF INTEREST STATEMENT

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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