Scanning the Solderability of a Surface

A new method of solderability assessment can give a value for the time to start soldering and can provide data on changes in wettability and on the influence of component thermal properties on solderability

BY GERT BECKER

SUMMARY. A method on the basis of the wetting balance is described, with which it is possible to scan the solderability of a surface and to express the findings in objective statistical values. With this method it is even possible to detect the deterioration of the solderability of a component lead due to the heat loss to the component body.

Introduction

It is estimated that about 70% of all soldering defects can be traced back to bad solderability (Ref. 1, 2). This is the reason why many ideas and much work are laid down in improving solderability by the one or other means. These efforts are understood when one realizes that electronic production has been increasing in volume simultaneously with increased demands on the reliability of the electronic circuitry.

In the USA, the main effort to improve soldered joint reliability has gone into the development of production methods, especially in the development of water soluble fluxes. In Europe, great efforts have been made to improve the solderability of the material to be soldered and, with this, to form the basis for the formation of a reliable solder joint. On the other hand, it is felt that there is a lack of adequate solderability testing methods.

The lack of adequate testing methods has led to a development of new and exact solderability testing methods. In contrast to subjective methods which depend on an operator's individual judgement (such as the MIL STD 202, Method 208, dipping method), the new methods are objective and give a quantitative measure of solderability.

Some of the quantitative test methods are the IEC Solder Globule Method and the wetting balance method widely known as the meniscograph method. With these objective methods, however, an overall impression of the solderability of the surface cannot be gained with one single measurement. One way to overcome this situation was to carry out many measurements and to treat them statistically. This statistical approach to solderability assessment still does not give all the wanted information. For example, it is difficult to get information on how the solderability varies over the length of the termination, or if the solderability is uniform and good over the whole length of the termination.

There is other information which can be important for practical soldering but which so far can be gained only by special measurements. For example, it is important to know how long it takes to start the soldering process at the end of the component lead, or how much the solderability of the component lead adjacent to the component body is influenced by the cooling of the component body acting as a heat sink. This certainly has consequences on how the component must be mounted on the board prior to soldering or on the design of the component itself.

The IEC Solder Globule method measures the time from the very first moment when the solder globule touches the component wire, flows around it and elapses at the top of the wire. Here, the solderability is measured on one single line of the component lead, a line around the circumference. This method has the advantage that a defined simple measure is obtained—i.e., wetting time. Even in the case of wetting balance (meniscograph) where the component lead is dipped into the solder bath, solderability is in fact measured at a line around the component lead.

The wetting balance method (Ref. 4) provides wetting force acting on the sample/time in a form of a complex curve. This curve gives a measure for the wettability or solderability of the sample. Considerable efforts have been made to study and to understand the obtained curve and to develop guiding rules for its evaluation.

The method described here is basically a modified wetting balance method where the sample is dipped very slowly into the solder bath. This method makes it possible to measure the solderability sequentially (scanning) over the whole length of a component lead. Tests with the slow wetting balance method have been reported in the literature (Ref. 5, 6, 7).

The Scanning Solderability Test

The disadvantage that there is no objective method which gives a value for the solderability of the whole surface, was the reason for developing a new test. The test, in principal, is based on the findings of Lenz (Ref. 3) but uses the wetting balance method. Lenz describes how the material properties—i.e., the heat conductivity, the heat capacity and the dimensions of the sample as well as the aging—determine the wetting speed. This means that a specimen, which is dipped into a solder bath with a speed that is low enough, will wet or solder simultaneously with the dipping. Lenz found that solderable materials with dimensions that are normal for electronic production, and even normally aged material, will solder at dipping speeds less than 3 mm/s (0.12 in./s).

The dipping speed for the normal wetting balance method today is specified to 20 mm/s (0.79 in./s) (Ref. 9). Since a dipping speed of 1 mm/s (0.04 in./s) is suggested for the scanning wetting balance method, it may be useful to com-

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pare both the fast and the slow wetting modes. In the fast mode the sample normally is dipped into the solder bath for a length of 2 to 5 mm (0.08 to 0.20 in.) within 0.1 to 0.25 s. Figure 1 shows that a 1.2 mm (0.05 in.) diameter and a 10 mm (0.39 in.) long wire needs 1.4 s to reach the maximum wetting force. The consequence is that the sample is wholly dipped into the solder bath before it reaches soldering temperature. Thus the wetting curve in the fast mode indicates:

1. How fast the sample is heated.
2. If the flux can react.
3. What time it needs to react with the solder and the sample.

In other words, the surface properties along the sample up to the dipping depth are measured under conditions which actually are not intended. They are uncontrolled and, other than wetting speed, do not provide other information on the solderability along the sample.

At the end of the test (at the dipping depth), a measure will be available for only the wetting quality (wetting force). Thus, it is not possible with the fast dipping mode to measure the surface properties along the sample.

The slow dipping mode of 1 mm/s (0.04 in./s) is suggested with respect to the findings of Lenz. For the above mentioned wire it takes 1.4 s to reach the maximum wetting force. In other words, with a dipping depth of 1.4 mm (0.06 in.) a stable test condition is obtained where the only varying factor in the test is the surface condition of the sample — and it is this that we want to measure in a solderability test.

After 1.4 mm (0.06 in.) or 1.4 s, the wire has reached the required soldering temperature and thus has the ability to wet properly. The flux has been preheated and has had time to work until the solder approaches. Thus, it is possible to measure the solderability (wetting force) over the length of the sample by further dipping it into the solder bath. The length which can be dipped into the bath can be calculated from the buoyancy force. A practical advantage which increases the

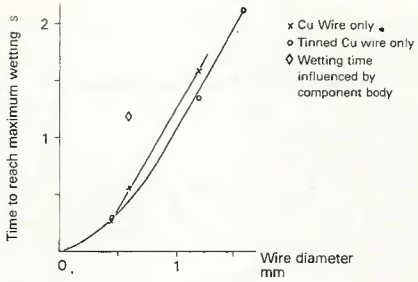

Fig. 1 — Time needed for maximum wetting in a dipping process

accuracy of the measurement with the low dipping speed is that shock waves are avoided when the sample penetrates the solder bath (Ref. 5).

The scanning wetting balance method has the advantage of giving a value for the time it takes to start the soldering process. Also, it shows how the wettability changes over the length of the component lead and gives an indication on whether, and how much the solderability is influenced by the thermal properties of the component — Fig. 2.

The tests described here were carried out with an in-house built wetting balance tester according to the principles described by ten Duis (Ref. 4) and conforming with IEC TC50C(secr) 40 (Ref. 9) and the additional feature of a dipping speed range of 0.5–30 mm/s (0.02–1.18in/s), withdrawal speed range 0.5–30 mm/s, (0.02–1.18 in/s) dwell time 0–20 s and solder bath temperature range of 50–450°C (122–842°F).

The Measuring Principle

Before any solderability testing with the scanning method can be made, it is necessary to establish two parameters for the evaluation of the normal wetting curve by means of the reference wetting curve. For regularly shaped leads it is possible to calculate the reference wetting curve from the dimensions of the sample. For irregularly shaped leads, the calculation is difficult. In this case, it is much easier to actually measure and establish the reference wetting curve under specified experimental conditions and to use this curve for further evaluation.

The first parameter needed is the maximum possible wetting force for the given type of sample. The second parameter gives us the starting point from which the evaluation has to be carried out. The reference wetting curve is obtained under nearly perfect conditions. The sample is prepared by suitable treatment to achieve the highest possible reference wetting force (RWF). This treatment can involve a pickling process, the usage of corrosive fluxes, and higher soldering temperatures, or it can be a combination of these treatments. Another method which has been proved effective is to dip a sample repeatedly into the solder bath and to take the curve with the highest achieved wetting force as the reference (Ref. 9).

As the sample is dipped into the solder bath with the slow speed of 1 mm/s (0.04 in./s), the sample starts soldering nearly at once. It takes only a very short time (due to the activation of flux and the heat capacity of the specimen) for the meniscus of the solder to reach its proper height which it will keep during the whole dipping process. This time is indicated by the 0-A of the wetting curve shown in Fig. 3. The numerical evaluation of the curve starts at point A. The part A-B indicates the dipping process, itself.

At point B, the movement of the specimen into the bath comes to an end, and an increasing amount of the meniscus is observed. This means that the wetting force is increasing, because the static wetting force is larger than the dynamic wetting force. At point C the build-up of the meniscus is finished, and the highest possible wetting force is recorded. Point G is marked on the buoyancy curve above point C. The distance G-C is measured and represents the RWF which is put equal to 100% wetting. B-D represents the dwell time and D-E is the part during which the specimen is drawn out of the bath.

From the dimensions of a regularly

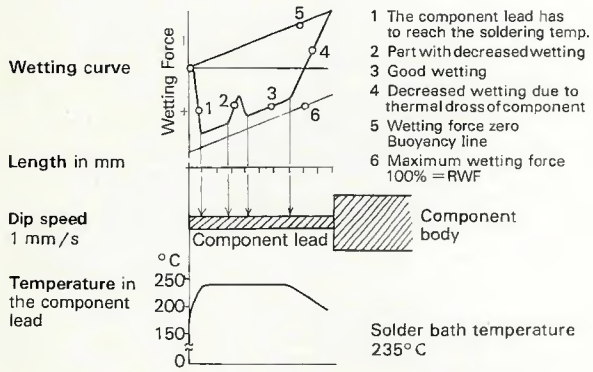

Fig. 2 — The scanning solderability test method

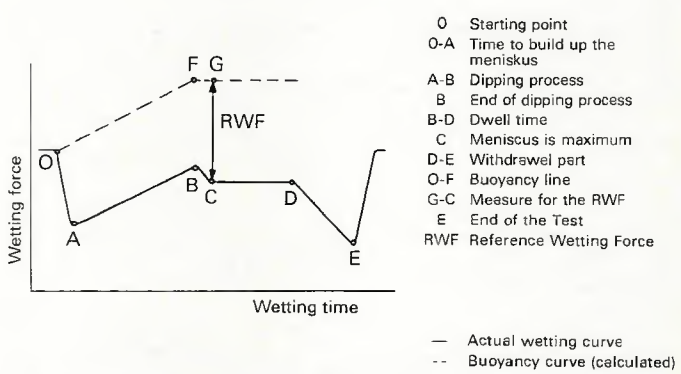

Fig. 3 — Explanation of the wetting balance curve for the scanning method

shaped sample, the buoyancy curve is calculated and drawn into the graph—dotted line in Fig. 3. Due to the low dipping speed, the buoyancy line reaches its maximum first when the dipping process has come to a standstill at point F, which corresponds to point B on the wetting curve.

Evaluation of the Wetting Balance Curve and Its Presentation

Having established the starting point and the RWF, the solderability of the surface of the actual sample can be scanned. Of course, the samples must have the same size, shape and base material. The scanning solderability method is a new method of solderability assessment. Therefore, it has not been possible to come to a general agreement as to how to present the obtained curves in the best way. Therefore, a few different methods of interpretation are described.

First Method

The first method is a simple and fast one—Fig. 4. The buoyancy curve is drawn as shown in Fig. 3. Parallel to 0-F in Fig. 4, two lines are drawn as an envelope of the curve. The distance from the buoyancy curves to the upper envelope H and the lower envelope I, is measured and compared with the RWF and expressed as a percentage of the RWF. In this way a number of curves can be evaluated. The measured values can be given either as the maximum and minimum percentage of the RWF, or as the mean value with the spread.

Second Method

A second method is only a slight change from the first method. With this method (Fig. 4) one has to agree on what percentage of the RWF shall be regarded as the limit values for the solderability. A value of 70% is suggested. From the curve in Fig. 4 it can be derived that 80% of this specific sample has a solderability better than 70%, while 20% lies under the limit value of 70%. Here there must be a judgment or agreement on whether the 20% shall lead to a rejection or not. As component leads are soldered at a defined distance from the component body, a systematical bad solderability at this point of the component lead must lead to rejection.

Third Method

If a more detailed analysis of the wetting forces is necessary, a third method can be applied. The wetting line A-B is divided into a suitable number of segments—Fig. 5. Each segment corresponds to a defined part of the surface of the sample. The distance from the buoyancy curve to the respective point is measured and given as a percentage of the RWF.

A number of curves are evaluated in this manner. The measured values are arranged in sequence and plotted in a diagram—Fig. 5. A histogram is obtained that tells us exactly how many percent of the overall scanned surface had what solderability.

In the example given, tests were carried out on 10 specimens with a length of 10 mm (0.39 in.) each. Each curve obtained was divided into 20 parts. This means that, for each 0.5 mm (0.02 in.) the solderability value was determined. Thus, a total of 200 measurements were carried out.

The histogram in Fig. 5 shows that the 100 mm sample length (80% of which is equivalent to 80 mm) had a solderability of 70% RWF and only 5% = 5 mm, a solderability of 40% RWF. Such a material should be considered as good. With the division of the curve, the measuring of individual values can be easily done using a computer and display that calculates and prints out a histogram such as that indicated in Fig. 5.

Compared to the solder globule or regular wetting balance method, solderability scanning saves considerable testing time. As demonstrated above, 10 samples produced 200 experimentally meaningful points. To produce the same number of data points, the solder globule or wetting balance would require 200 samples; 200 tests would be needed to evaluate the solderability of spatial differentiation of a component lead.

Purely Visual Assessment of Wetting Balance Curve

By comparing the wetting curve with the buoyancy line, valuable information can be gained; this, of course, can be treated numerically as shown below.

An 0.6 × 0.6 mm (0.024 × 0.024 in.) electrolytically tinned phosphor bronze wire was dipped 11 mm (0.43 in.) with a speed of 1 mm/s (0.04 in/s). Curves as shown in Fig. 6A were gained. The solder was Sn60Pb40 and the flux activated according to IEC 68-2-20. The solder bath temperature was 250°C (482°F). Figure 6A shows that about the first millimeter—or 1 s—was needed to heat the sample before it reached fair solderability. For further 10 mm (0.39 in.) the solderability of the sample was very uniform. The drop at 11th millimeter, however, shows that the solderability of the specimen compared with the solderability achieved during the dwell time was not optimum.

In Fig. 6B the solderability is good for the first 2 mm (0.079 in.), decreases constantly the next 1.5 mm (0.06 in.), is then constant for 1 mm (0.04 in.), increases slightly for 3 mm (0.12 mm) and rapidly for 2 mm (0.079 in.). At the end of the tested length the solderability is the best. Figure 6C shows at the beginning good solderability which, after 2 mm (0.079 in.), decreases constantly and considerably. The solderability becomes eventually so poor that it takes 1 s after the end of the dipping process before the meniscus is able to increase; 2 s more are needed to build up the meniscus to its highest value.

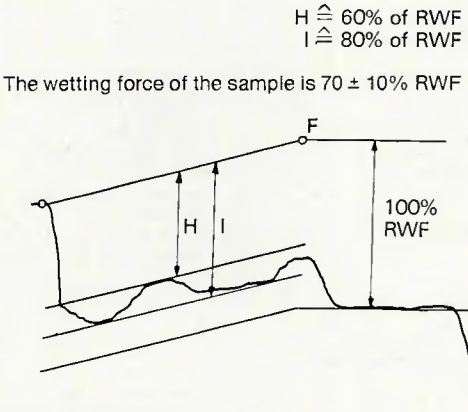

Fig. 4—Numerical evaluation of the wetting balance curve—method 1

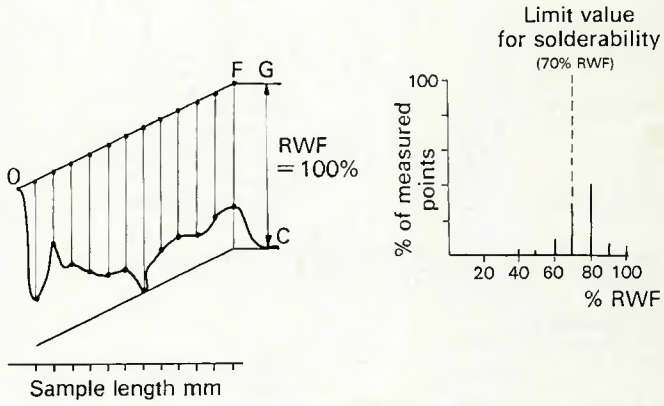

Fig. 5—Numerical evaluation of the wetting balance curve—method 2

Since the dipped part of the sample was 11 mm (0.43 in) and the length of the recorded trace 95 mm (3.74 in.), 1 mm (0.04 in.) of the sample corresponds to roughly 10 mm (0.39 in.) of the traced curve. This means that the resolution of the solderability over the surface is indeed very good and that an exact measurement of the solderability for a specific place on the sample can be made.

Heat Sink Effects of the Component Body

When applying the scanning solderability test to rather small components, in certain cases the solderability on the component lead near the component body was found to decrease. It is known that the solderability can be influenced either by the surface properties of the sample or by its thermal properties, or both. In (Ref. 10) Klein Wassink describes the influence of the thermal properties on soldering and suggests for this phenomenon the expression, thermability. There is the possibility that the scanning method can indicate decreased solderability as a function of the thermal demand of the component body acting as a heat sink. To show this, the following tests were carried out.

Well solderable copper wires with diameters of 0.6 and 1 mm (0.024 and 0.039 in.) respectively were inserted into 25 x 7.2 mm (0.98 X 0.28 in.) diameter aluminum and 47 x 10 mm (1.85 x 0.39 in.) diameter copper cylinders. The function of the copper or aluminum cylinder was to simulate the component body, e.g., a large MP capacitor. The length of the wire outside the cylinder was adjusted to 3.6-5 and 10 mm (0.14-0.20 and 0.39 in.) respectively. The shortest length was chosen due to the fact that a printed wiring board normally has a thickness of 1.6 mm (0.06 in.) and that the lead is allowed to stand out at the solder side of the board for 2 mm (0.078 in.). For comparison, the wetting curve for a copper wire without a metal cylinder was taken.

The result of the test is shown in Fig. 7 for the small aluminum cylinder with the 0.6 mm (0.024 in.) wire diameter. The sharp upward bend in the curves of Fig. 7 is characteristic of the fact that the wetting is no longer determined only by the surface properties of the copper wire; wetting also is influenced by the thermal demand of the component body, which lowers the temperature on the wire surface and thus causes decreased wetting followed by non-wetting. It should be mentioned, however, that a sharp bend in curve may also be obtained when non-solderable material, such as the component material, may have crept during the manufacturing process onto the lead. But this case is easily discernable from our heat sink case.

From the diagram in Fig. 7 it can be seen that the shortest wire (3.6 mm or 0.14 in.) only for a length of 1.4 mm (0.06 in.) reaches a RWF of 50% which must be regarded as insufficient. When soldering such a component lead to a PWB, this would mean that a safe solder connection cannot be obtained under normal soldering conditions.

A length of 2.2 mm (0.087 in.) from the component body is not solderable according to the diagram due to the thermal demand of the component body. If the wire length is increased to 5 or 10 mm (0.20 or 0.39 in.) , the 2 mm (0.078 in.) near the component body will not solder.

In our case two conclusions must be drawn. The first is that the design of the component is unsuitable if the component body is required to be flush mounted to the component side of the PWB. The second conclusion is the component lead must have a certain minimum length if such a component must be soldered on a PWB. This is necessary to allow proper wetting; a special mounting technique is required. The component body must not be closer than 2.2 mm (0.09 in.) to the component side of the PWB.

As could be expected, both thicker wire, and the larger copper body with its higher thermal conductivity and capacity resulted in decreased wetting to total non-wetting—Fig. 8.

Conclusions

With the knowledge we have today on solderability testing, it is reasonable to predict that the scanning method of solderability assessment may become widely used to determine the solderability of component leads. The wetting balance method as it is used today with the high dipping speed will retain advantages for the study of material properties such as the efficiencies of fluxes and solders, and for material development. The scanning method will also be of great interest for measuring the effects of the cooling by the component body on solderability.

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References

1. Mathes, H., and Gamalski, J. 1975. *Praktische Anwendungen des Weichlötens Der Praktiker* heft 9.
2. Keller, Joseph D. A review of soldering technology. Soldering Seminar; reprint Hollis Engineering Inc.
3. Lenz, E., and Kramer, P. 1970. Werstofftechnische vor ussetzungen für den automatischen lötprozess in der elektrotechnik. *Feinwerktechnik* Juli, heft 7: 273-320.
4. ten Duis, J. A., and van der Meulen, E. 1967. Measurement of the solderability of components. *Philips Technical Review* 28, no. 12: 632-634.
5. Peth, H., 1975. Die benetzungswaages,

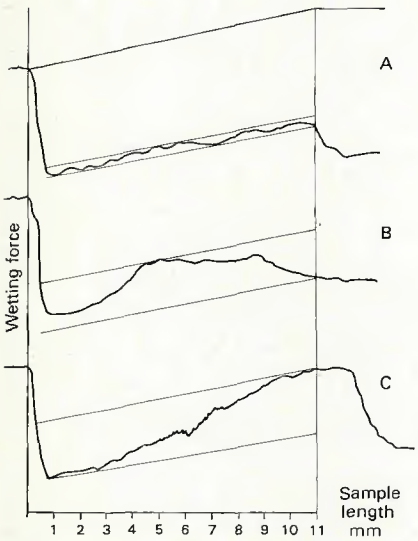

Fig. 6 — Examples of solderability scanning curves

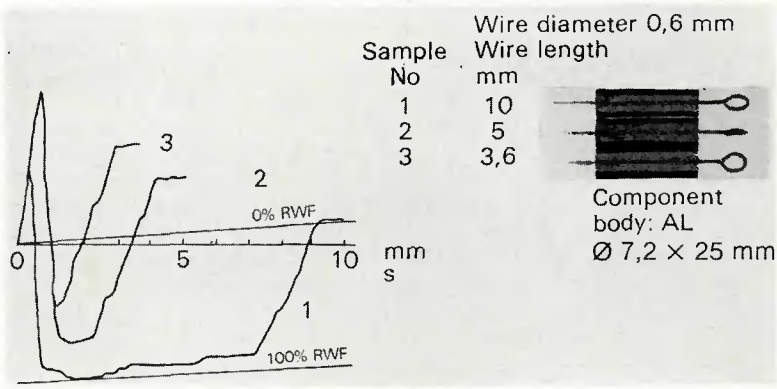

Fig. 7 — Influence of the component body heat drain on the wetting of the component lead

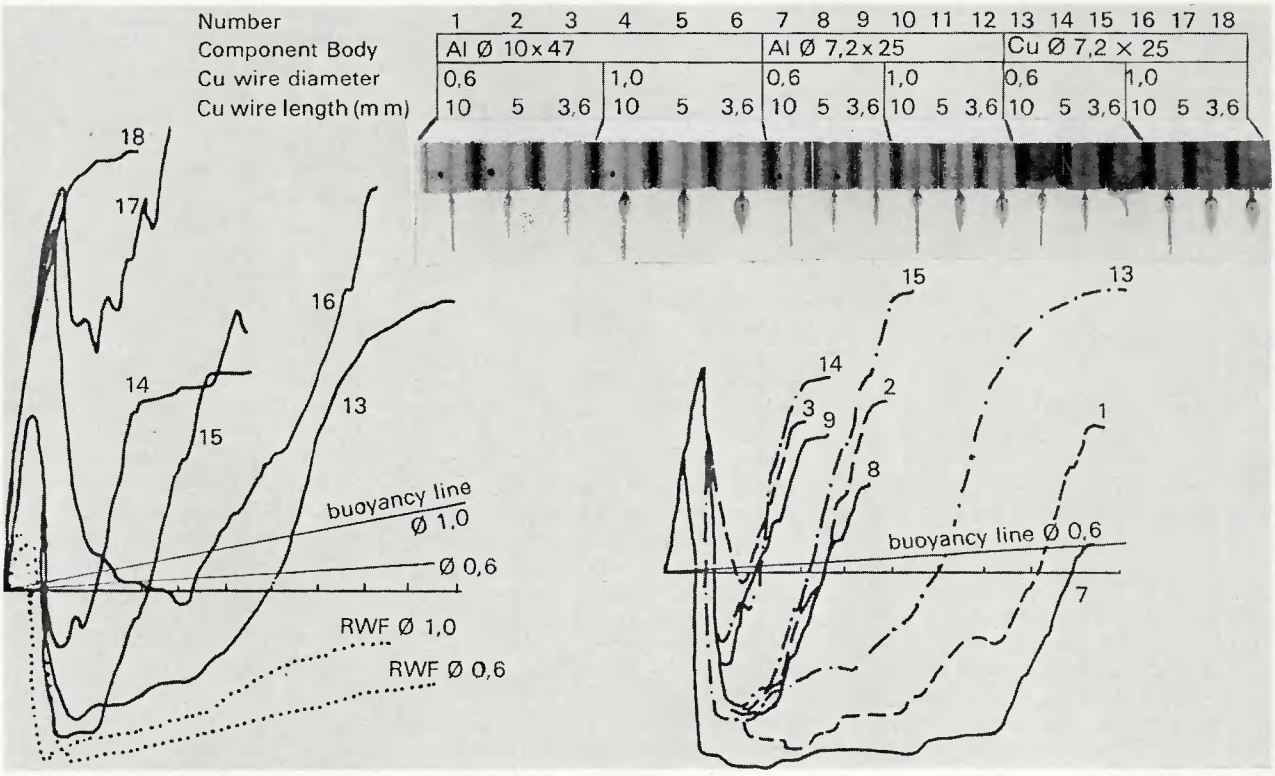

Fig. 8—Heat sink effect of component body and lead dimensions on solderability

ein neues hilfsmittel bei der prüfung von weichlötflussmitteln. *Journal of Materials Technology.* 6 Jhg, no. 11: 367-376.

6. Hartmann, H. J. 1976. Extended application of the wetting balance for the evaluation of flux-free soldering processes. *DVS Bericht* no. 40: 149-156. Dusseldorf, Germany: Deutscher Verlag für Schweisstechnik (DVS) GmbH.

7. Comerford, M. F., and Skelly, M. E. 1980. Slow speed solderability testing. *Proceedings of the national packaging and productions conference:* 587-591.

8. Becker, G. 1968. Ein auswerteverfahren für versuche zur bestimmung der löteignung. *Schweissen & Schneiden* heft 7: 318-322.

9. IEC TC (Secr) 37. 1980. Solderability testing by the wetting balance method. Addition to publication 68-2-20: Test T: soldering, July.

10. Klein Wassink, R. J. 1978/79. The thermal behaviour of electronic components during soldering. *Philips Technical Review* 38, no. 4/5: 135-142.