wieland

Peter Stahl, Julian Guter, Dr.-Ing. Robert Zauter

A question of assessment – discussion of the evaluation standard for soldering tests with lead-free solder on copper and copper alloy strip

---

Published in the proceedings of

Anwenderkongress Steckverbinder 2024

Congress for Users of Connectors 2024
Würzburg, Germany, 03. – 05.06.2024

Wieland Werke AG
Vogel Convention Center VCC
Würzburg, 2024, June 03. – 05.

A question of assessment – discussion of the evaluation standard for soldering tests with lead-free solder on copper and copper alloy strip

Peter Stahl, Julian Guter, Dr.-Ing. Robert Zauter

Wieland-Werke AG, Graf-Arco-Str. 36, 89079 Ulm, Germany

Abstract

DIN EN IEC 60068-2-20 is increasingly being used to specify the soldering suitability of copper and copper alloy strip, in addition to its intended area of application for conductors / electrical connections of electrical components, called “leads”. In the present study, solder tests described in the standard were carried out with SnPb40 solder and Sn96.5Ag3Cu0.5 solder and the results are discussed. These show that, in addition to the expected influence of the composition of the solder on the soldering result, the evaluation standard used in the visual inspection is particularly decisive for the assessment of the soldering result. The question, whether locally very thin solder layers are critical or not, is decisive for the evaluation of the appearance of the solder layer formed on the samples when using the lead-free solder Sn96.5Ag3Cu0.5. If such appearances of solder layers are classified as critical, the soldering suitability of copper and copper alloys with Sn96.5Ag3Cu0.5 solder must generally be assessed as critical. Even very clean sample surfaces, which were adjusted by harsh pickling immediately before the soldering test with Sn96.5Ag3Cu0.5, after the test show these appearances layers. An open discussion of the evaluation standard when using lead-free solders is therefore necessary.

1. Background

After the invalidation of DIN 32506 in 2017, according to which strip samples submitted to the immersion test were tested “with regard to their wetting on the basis of reference samples” [1], there is no longer a standardized soldering test for strip made of copper and copper alloys. In the absence of an alternative, DIN EN IEC 60068-2-20 [2] is therefore often applied to strip. This standard describes soldering tests with both, lead-free and lead-containing solders on leads extending from components.

In daily practice, the soldering test according to DIN 32506 and its acceptance criteria continues to be accepted by many users of copper strip, as it is considered sufficient for numerous applications. Nevertheless, the application of DIN EN IEC 60068-2-20 is also common for strip made of copper and copper alloys, so that a detailed examination of the specifications of the standard and the interpretation of the soldering results from the perspective of a semi-fabricate manufacturer is required. In principle, the dip tests standardized in DIN EN IEC 60068-2-20 can also be carried out on strip samples with both, leaded and lead-free solders, but the soldering results observed are worthy of discussion.

2. Execution of the soldering test according to DIN EN IEC 60068-2-20

DIN EN IEC 60068-2-20 is divided into two sections. The first part describes testing the solderability of wire and flat connections using the lifting immersion process (test Ta). This first section of the standard is the subject of the present investigations because this test methodology is increasingly being applied to strip materials made of copper and copper alloys. Our investigations were carried out according to test Ta, test method 1 (soldering bath). Aging of the samples before testing has not been applied.

The second part of the standard deals with the test of soldering heat resistance, whereby the resistance of a test specimen to the heat generated during soldering is to be tested (test Tb). This section of the standard is not applicable to strip made of copper and copper alloys and is therefore not considered in this article.

2.1. Sampling process

As required by the standard, the samples were tested "as delivered". For this purpose, appropriate strip sections were branched off from the regular strip production at Wieland-Werke AG. When selecting the samples, emphasis was placed on a wide range of alloys and a large range of strip thickness between thin and thick, see table 1. The branched strip sections were individually wrapped in paper, packed in plastic bags and stored at room temperature until testing. Test specimen for the soldering test in the size 10 x 75 mm were cut from the strip material using guillotine shears. Testing of the samples in accordance with DIN EN IEC 60068-2-20 began immediately afterwards.

Tab. 1: Samples taken, alloys and strip thicknesses

Wieland-K32	**Cu-ETP**	0.2 mm	0.6 mm	0.78 mm
Wieland-K09	**Cu-OFE**	0.2 mm	0.57 mm	1.0 mm
Wieland-K88	**CuCrAgFeTiSi**	0.2 mm	0.5 mm	
Wieland-K75	**CuCrSiTi**	0.2 mm	0.6 mm	0.8 mm
Wieland-K76	**CuNiSiP**	0.3 mm	0.6 mm	
Wieland-K73	**CuNi1ZnSi**	0.2 mm		
Wieland-K55	**CuNi3Si1Mg**	0.2 mm	0.48 mm	0.7 mm
Wieland-M30	**CuZn30**	0.3 mm	0.7 mm	1.0 mm
Wieland-M38	**CuZn38**	0.3 mm	0.6 mm	0.8 mm
Wieland-B14	**CuSn4**	0.2 mm	0.65 mm	
Wieland-B16	**CuSn6**	0.3 mm	0.6 mm	1.0 mm
Wieland-B18	**CuSn8**	0.15 mm	0.6 mm	
		<0.4 mm	**0.4–0.7 mm**	**0.7–1.0 mm**
		“thin”	**“medium”**	**“thick”**

All samples listed in Table 1 are bare strip samples. For comparison purposes, four additional samples of hot-dip tinned strip were examined:

– Wieland-K75 (CuCrSiTi) 0.3 mm with 1–3 µm Sn
– Wieland-K75 (CuCrSiTi) 0.4 mm with 2–4 µm Sn
– Wieland-K75 (CuCrSiTi) 0.8 mm with 1–3 µm Sn
– Wieland-K55 (CuNi3Si1Mg) 0.6 mm with 1–3 µm SnAg

The wetting behavior of the solder on tin coated strip surfaces is generally very good and does not cause any problems.

2.2. Test procedure and conditions

DIN EN IEC 60068-2-20 stipulates the use of SnPb, Sn96.5Ag3Cu0.5 (SAC) or Sn99.3Cu0.7 for test Ta, test method 1 (solder bath). The present study was limited to a comparison of the most commonly used solders SnPb and Sn96.5Ag3Cu0.5.

In the immersion test, in a first step the sample is immersed in a flux and then hung up to dry. This allows excess flux to run off. The flux should not be activated. However, if a non-activated flux is unsuitable, a slightly activated flux may also be used. As it is already known from preliminary investigations that some alloys from Table 1 cannot be wetted well with non-activated flux, a slightly activated flux was selected and this was used for all alloys in order to ensure comparability of the results.

After the drying time of the flux, the sample was immediately immersed in the solder bath. Immediately before this test, the slag on the surface of the molten solder was removed with a scraper in accordance with the standard.

In accordance with the parameters in Table 2, three samples per material/thickness combination from Table 1 were tested with both leaded SnPb40 solder and lead-free SAC solder (Sn96.5Ag3Cu0.5).

Tab. 2.: Test conditions for flux application and the immersion test in the solder bath according to DIN EN IEC 600682-2-0 Test Ta, test method 1 [2]. Percentages are by weight.

	parameter	DIN EN IEC 60068-2-20 with **lead-containing** SnPb solder	DIN EN IEC 60068-2-20 with **lead-free** SAC solder
flux	composition	25 % rosin dissolved in 75 % isopropanol diethylammonium chlorid: 0.1 % ± 0.01 %	
	drainage / drying time	60 +/- 5 s	

solder bath	composition	L-Sn60Pb (Sn: 60 %, Pb: 40 %)	SnAg3Cu0.5 (Ag: 3.0 – 4.0 % Cu: 0.5 – 1.0 %)
	temperature	235 +/- 3 °C	245°C +/- 3 °C
	immersion speed	25 mm/s	
	immersion depth	25 mm	
	dwell time	2 +/- 0.2 s	3 +/- 0.3 s
	surfacing speed	25 +/- 2.5 mm/s	

3. Results

3.1. Evaluation of the samples

According to DIN EN IEC 60068-2-20, the test specimens must be subjected to a visual inspection under appropriate lighting and with the aid of a stereomicroscope at 4x to 100x magnification for evaluation.

The visual inspection is recognized as passed if the “surface relevant for soldering” is covered with a layer of solder, whereby only “a few randomly distributed defects such as pores or unwetted or removed areas” [2] are permitted. The solder layer must be free of defects on “at least 95 % of the critical area of each individual connection”.

The reference surface for the strip samples was defined as the entire area wetted by the solder. During the investigation, care was taken to ensure that the defects defined in the standard account for a maximum of 5 % of this reference area. Furthermore the standard requires for lead-containing solder, that the solder must be smooth and shiny [2].

3.2. General observations

During the evaluation of the samples listed in Table 1, which was carried out in accordance with chapter 3.1, three different appearances of the solder coating after the soldering process were observed (Fig. 1).

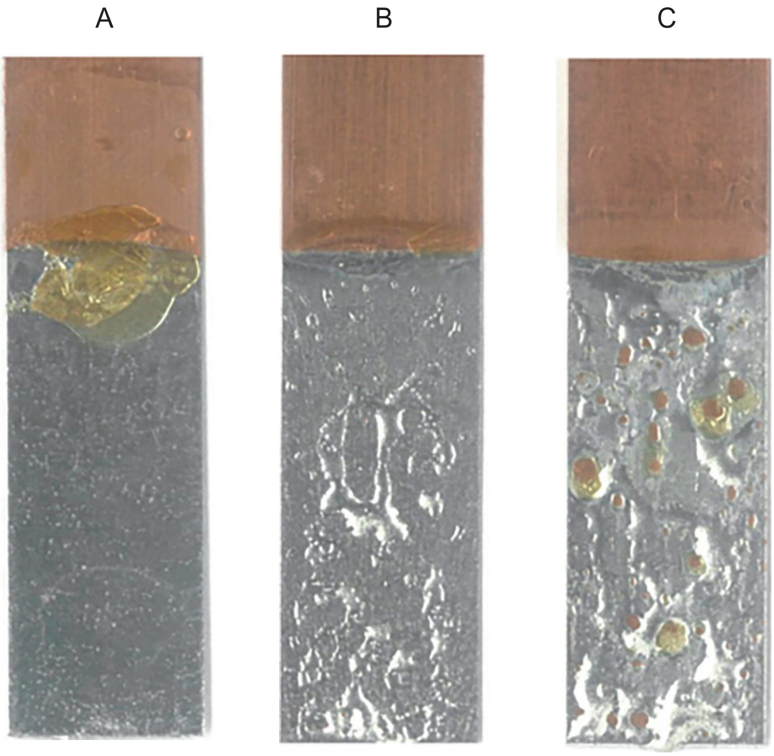

Fig. 1: Appearances of the solder layer

A – smooth and shiny
B – completely wetted with unevennesses of the solder surface
C – incompletely wetted with unevennesses on the solder surface

In this context, the following standardized definitions of terms are essential for the further discussion of the results:

"wetting":	Formation of an adhesive solder layer on a surface. Note: A small wetting angle indicates wetting.
"non-wetting":	Inability to form an adherent solder layer on a surface. Note: In this case, the wetting angle is bigger than 90°.
"de-wetting":	Contraction of the solder that has previously been spread out on a solid surface. Note: In some cases, a very thin solder film may remain. When the solder contracts, the wetting angle increases.

Regardless of the solder used, the sample material and the strip thickness, the appearances of the solder layer in Fig. 1 raises the question of whether and to what extent these must be interpreted as defects in accordance with the definitions in DIN EN IEC 60068-2-20 (under Section 3) or may be interpreted as good.

Appearance A

In this case, the solder layer has a smooth, shiny and even surface. Even under maximum magnification (100x), no defects as defined in DIN EN IEC 60068-2-20 can be seen. The layer thickness is approx. 5-10µm (see Fig. 2).

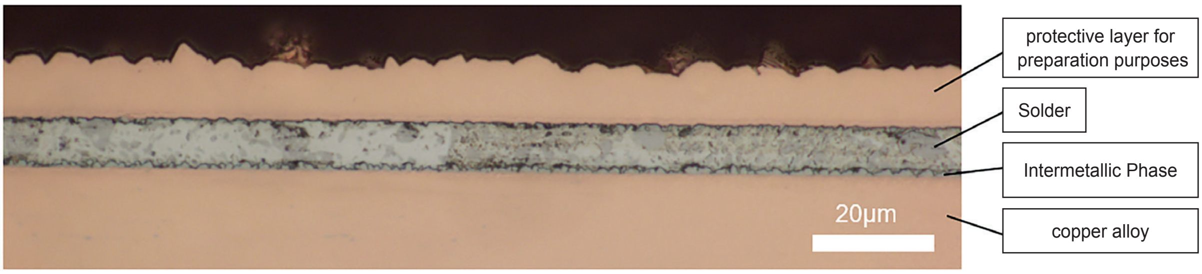

Fig. 2: microsection through a uniformly thick solder layer of appearance A

Appearance B

As with appearance A, the solder has completely covered the surface. Non-wetting is not recognizable. However, unevenness of the solder surface is clearly recognizable, which is visible and measurable in clearly different solder coating thicknesses, which vary in the range between 2 and 50µm. According to DIN EN IEC 60068-2-20, such a solder coating can be regarded as wetting, as the adhesive coating is clearly recognizable. The micrograph also shows the small wetting angles at the points where the solder has contracted (Fig. 3). These are clearly below 45°.

On the other hand, such an appearance of the solder coating can also be assessed as de-wetting in the sense of DIN EN IEC 60068-2-20, as the solder has contracted in some places. Unfortunately, the standard does not specify how large the wetting angle or how small the “very thin solder film” must be in order to clearly characterize de-wetting. With the help of metallographic examinations, it can be determined that free tin and thus an adhesive solder layer in the sense of DIN EN IEC 60068-2-20 is also present in the thinly wetted areas (Fig. 4a). Fig. 4b shows the corresponding EDX line scan, which confirms this fact. The tin peak proves the presence of the “pure” solder on the intermetallic phase, via which the solder layer is bonded to the base material in a solid and firmly adhering manner.

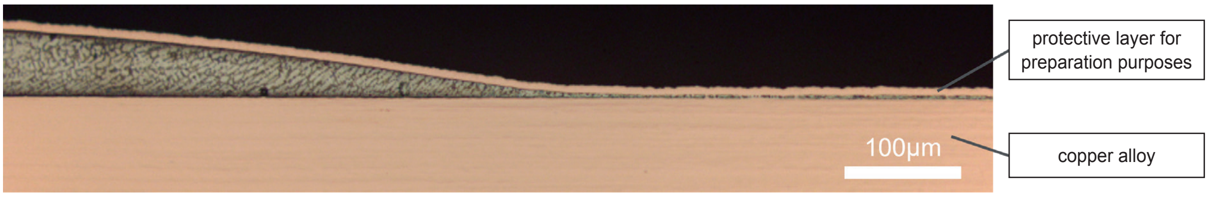

Fig. 3: Microsection through a point of contracted solder in appearance B

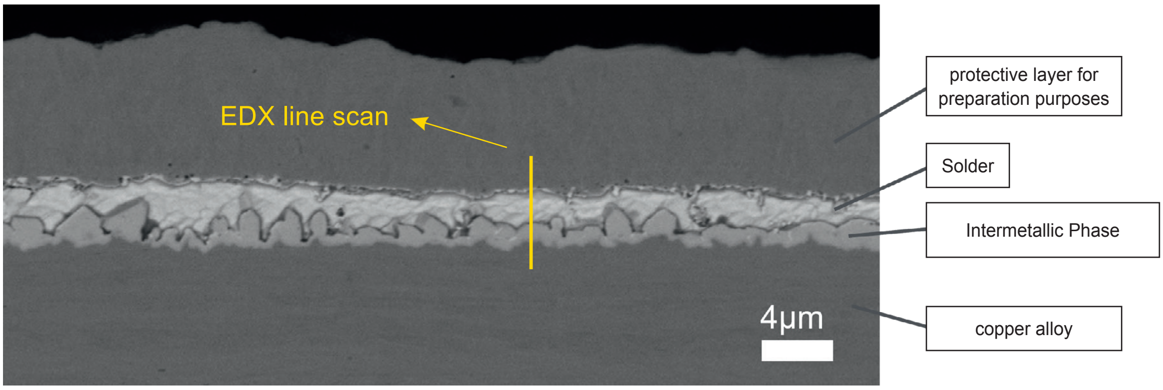

Fig. 4a: Position of the EDX line scan at a point of low solder coating thickness for appearance B

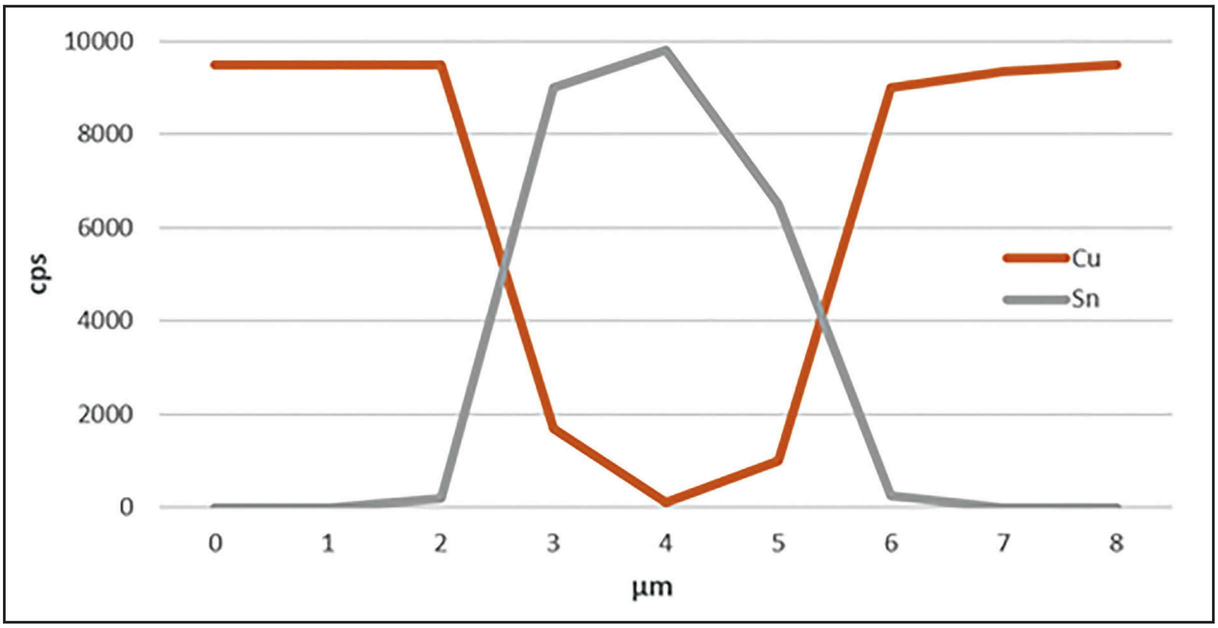

Fig. 4b: Result of the EDX line scan from Fig. 4a through a spot of low solder coating thickness with appearance B

Appearance C

This appearance clearly shows areas not covered by the solder, which are to be interpreted as non-wetting according to DIN EN IEC 60068-2-20, and thus represent a clear defect. Also present here are areas of contracted solder and very thinly wetted areas analogous to appearance B.

The decisive aspect in assessing whether or not a sample has passed the visual inspection in accordance with DIN EN IEC 60068-2-20 is therefore the question of whether or not the thinly wetted areas described under appearance B are interpreted as defects in the sense of the standard (de-wetting).

With this in mind, the samples evaluated in this study were subjected to two evaluation standards in parallel:

“mild” valuation standard:

Only the areas of the samples that do not have a solder layer are evaluated as defects
(see Fig. 1 – Appearance C).

“strict” evaluation standard

In this case, all those surface areas are evaluated as defects that either have no solder layer or only a very thin wetting with solder coating, which can also be interpreted as a de-wetting
(see Fig.1 – appearances B and C).

3.3. Evaluation of the sample groups

All samples in Table 1 were tested and evaluated in four groups, subdivided according to the solder used (SnPb40 or Sn96.5Ag3Cu0.5) and the evaluation scale (mild or strict). Thus, all material-thickness combinations listed there were tested twice (with different solders) with 3 samples each and then evaluated with two different evaluation scales.

3.3.1. Test procedure with leaded solder SnPb40

The solder layer had the appearance A in all tested samples (Fig. 5). Regardless of the severity of the evaluation standard applied, the samples tested with leaded solder SnPb40 in accordance with DIN EN IEC 60068-2-20 always pass the visual inspection.

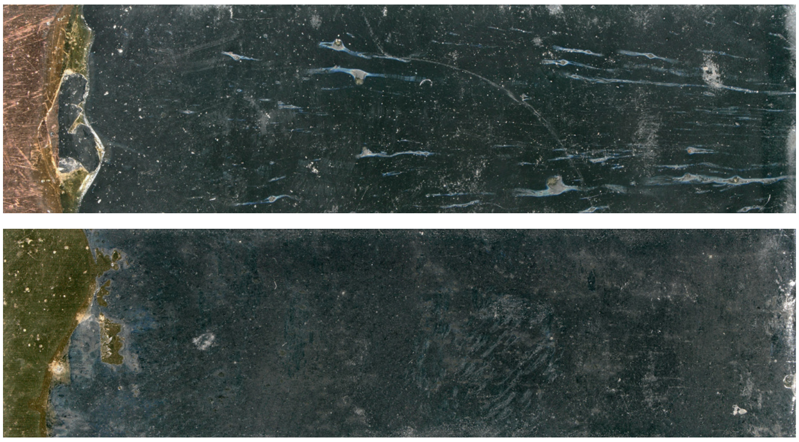

Fig. 5: Wieland-K09 (Cu-OFE, top) 0.2 mm and Wieland-M38 (CuZn38, bottom) 0.6 mm after carrying out the solder bath test according to DIN EN IEC 60068-2-20 with leaded solder SnPb40 – the solder layer has appearance A on both samples.

3.3.2. Test procedure with lead-free solder Sn96.5Ag3Cu0.5

The poorer wetting tendency of the lead-free solder Sn96.5Ag3Cu0.5 compared to the lead-containing solder SnPb40 is not compensated by the slightly higher solder bath temperature, neither by the slightly longer dwell time in the bath and also not by the slightly activated flux. As a result, all three appearances of the solder coating described in 3.2. can be observed in the tests with lead-free solder (Table 3). The evaluation result therefore depends heavily on the evaluation standard applied, see discussion in chapter 3.2.

Tab. 3: Observed appearances of the solder layer of Sn96.5Ag3Cu0.5 after testing according to DIN EN IEC 60068-2-20

Wieland-K32	**Cu-ETP**	B	B	A
Wieland-K09	**Cu-OFE**	A	A	A
Wieland-K88	**CuCrAgFeTiSi**	B	B	
Wieland-K75	**CuCrSiTi**	B	C	C
Wieland-K76	**CuNiSiP**	B	C	
Wieland-K73	**CuNi1ZnSi**	B		
Wieland-K55	**CuNi3Si1Mg**	B	B	B
Wieland-M30	**CuZn30**	B	B	A
Wieland-M38	**CuZn38**	B	B	A
Wieland-B14	**CuSn4**	B	C	
Wieland-B16	**CuSn6**	B	B	B
Wieland-B18	**CuSn8**	B	B	
		< 0.4 mm	**0.4 – 0.7 mm**	**0.7 – 1.0 mm**
		“thin”	**“medium”**	**“thick”**

3.3.2.1. Test procedure with lead-free solder Sn96.5Ag3Cu0.5 and application of the “mild” evaluation standard

If only the surface areas of the samples that do not have a solder layer are evaluated as defects, all samples pass the visual inspection, as none of the samples had more than 5 % unwetted areas as defined by DIN EN IEC 60068-2-20. This also applies to samples with appearance C.

In order to quantify the proportion of non-wetted areas in an exemplary and objective manner, a sample was evaluated using image analysis software. All non-wetted areas were marked manually and the sum of these areas was set in relation to the total area. This showed that even clearly visible non-wetting areas only make up a very small part of the total area evaluated. This makes the use of reference images and, at best, limit samples all the more important in the practical application of DIN EN IEC 60068-2-20. The use of quantitative image analysis software is not practical in view of the high volume of samples to be expected in the semi-finished products industry if the standard becomes more widespread in relation to strip samples.

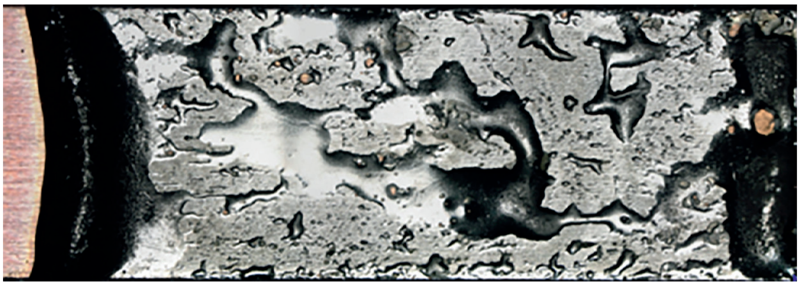

Fig. 6: Wieland-K75 (CuCrSiTi) 0.6 mm with a solder layer of appearance C

Applying the “mild” evaluation standard results in a defective area percentage of 0.32 % for this sample. The sample would therefore have passed the visual inspection in accordance with DIN EN IEC 60068-2-20.

3.3.2.2. Testing with lead-free solder Sn96.5Ag3Cu0.5 and application of the “strict” evaluation standard

If all those surface areas that either have no solder coating or only a very thin wetting with solder layer are evaluated as defects, many of the samples listed in Table 1 do not pass the visual inspection. The individual results can be found in Table 4.

Tab. 4: Results of the visual inspection after testing with Sn96.5Ag3Cu0.5 solder and applying the strict evaluation standard

Visual inspection passed = green field; Visual inspection failed = red field

Wieland-K32	**Cu-ETP**	B	B	A
Wieland-K09	**Cu-OFE**	A	A	A
Wieland-K88	**CuCrAgFeTiSi**	B	B	
Wieland-K75	**CuCrSiTi**	B	C	C
Wieland-K76	**CuNiSiP**	B	C	
Wieland-K73	**CuNi1ZnSi**	B		
Wieland-K55	**CuNi3Si1Mg**	B	B	B
Wieland-M30	**CuZn30**	B	B	A
Wieland-M38	**CuZn38**	B	B	A
Wieland-B14	**CuSn4**	B	C	
Wieland-B16	**CuSn6**	B	B	B
Wieland-B18	**CuSn8**	B	B	
		<0.4 mm	**0.4–0.7 mm**	**0.7–1.0 mm**
		“thin”	**“medium”**	**“thick”**

One of the samples that would not pass the visual inspection is the sample in Fig. 6, where 66.3 % of the total area would have to be assessed as defective. When applying the mild evaluation standard, this sample still passed the visual inspection without any problems.

In order to assess the extent to which the obviously significantly poorer wetting tendency of the Sn96.5Ag3Cu0.5 solder compared to the SnPb40 solder is due to a possibly insufficient strip cleanliness, an additional series of tests was carried out with all samples from Table 1 with lead-free Sn96.5Ag3Cu0.5 solder. In this case, however, the samples were pickled immediately before the test in order to guarantee the greatest possible surface cleanliness. The pickling was carried out for 10s in an active aqueous solution. The samples were then rinsed with water. Immediately afterwards, the samples were tested with Sn96.5Ag3Cu0.5 and the strict evaluation standard was applied again.

In addition to the removal of the oxide layer (Fig. 7), a further positive effect on the sample surface was demonstrated using hot gas IR spectroscopy. The carbon content on the surface was significantly reduced from 0.09 mg/dm² to 0.04 mg/dm².

Table 5 shows the results of the pickled samples, which indicate that even very careful cleaning of the sample surface does not significantly improve the wetting tendency of the Sn96.5Ag3Cu0.5 solder. When applying the strict evaluation standard, many samples still fail. Out of 24 material-thickness combinations that did not pass the visual inspection without the additional pickling, only 6 variants achieved such a good improvement in the appearance of the solder coating that the samples would have passed if the strict evaluation standard had been applied (see Table 4 and Table 5).

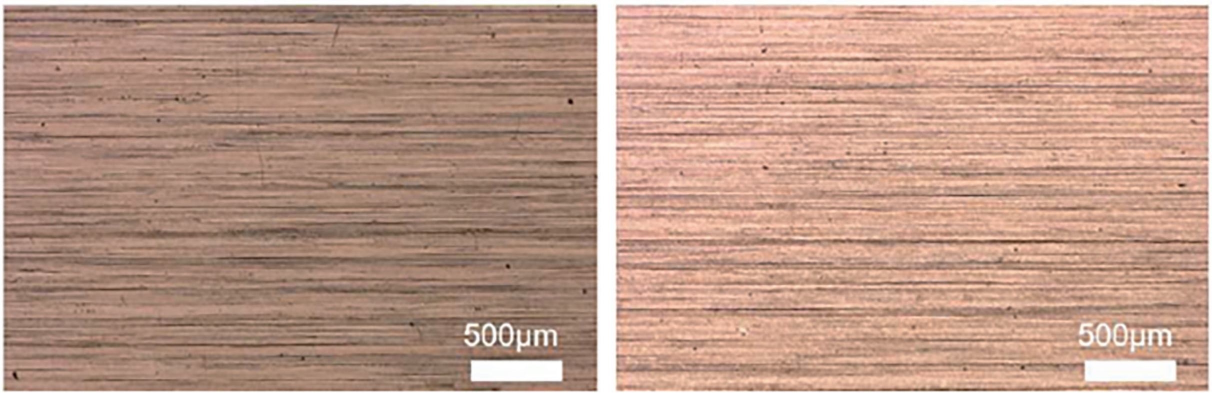

Fig. 7: unpickled sample surface on the left and pickled sample surface on the right
(Wieland-K75 (CuCrSiTi) 0.6 mm))

Tab. 5: Results of the visual inspection after testing with Sn96.5Ag3Cu0.5 solder with prior pickling and applying the strict evaluation standard

Visual inspection passed = green field; Visual inspection failed = red field

Wieland-K32	**Cu-ETP**	B	B	A
Wieland-K09	**Cu-OFE**	A	A	A
Wieland-K88	**CuCrAgFeTiSi**	B	B	
Wieland-K75	**CuCrSiTi**	B	C	C
Wieland-K76	**CuNiSiP**	B	C	
Wieland-K73	**CuNi1ZnSi**	B		
Wieland-K55	**CuNi3Si1Mg**	B	B	B
Wieland-M30	**CuZn30**	B	B	A
Wieland-M38	**CuZn38**	B	B	A
Wieland-B14	**CuSn4**	B	C	
Wieland-B16	**CuSn6**	B	B	B
Wieland-B18	**CuSn8**	B	B	
		<0.4 mm	**0.4–0.7 mm**	**0.7–1.0 mm**
		“thin”	**“medium”**	**“thick”**

3.3.3. Test procedure with leaded solder SnPb40 and lead-free solder Sn96.5Ag3Cu0.5 on the hot-dip tinned reference samples

The solder layer had the appearance A in all tested samples. Irrespective of the severity of the evaluation standard applied, these samples therefore always pass the visual inspection. This result was to be expected, as tin solder always wets very well on hot-dip tinned samples.

Fig. 8: Wieland-K75 (CuCrSiTi) 0.4mm with 2 - 4 µm thick hot-dip tinning after carrying out the solder bath test according to DIN EN IEC 60068-2-20 with leaded solder SnPb40 (top) and lead-free solder Sn96.5Ag3Cu0.5 (bottom)

4. Discussion and conclusion

DIN EN IEC 60068-2-20 describes, among other subjects, the testing of the soldering suitability of connections (leads) emerging from components by means of a solder bath and subsequent visual inspection. In the present study, its applicability to uncoated strip samples made of copper and copper alloys was examined.

It was found that the result of the standardized test depends heavily on the composition of the solder bath used (lead-free or lead-containing) and the evaluation standard used for the visual inspection.

It was found that the lead-containing solder SnPb40 consistently achieved excellent soldering results with a smooth and shiny appearance of the solder coating (appearance A) and thus always passed the visual inspection. This is independent of the type of material and the sample thickness.

However, when the test was carried out with the lead-free solder Sn96.5Ag3Cu0.5, different appearances of the solder layers were observed, the characteristics of which were discussed in this study. Depending on the severity of the evaluation standard applied during the visual inspection, a sample can be evaluated as passed or failed.

Therefore, when performing the test with the lead-free solder Sn96.5Ag3Cu0.5, the evaluation standard used for the visual inspection should be clearly defined between the business partners. Two gradations, the “mild” and the “strict” evaluation standard were discussed.

Literature

[1] DIN 32506

[2] DIN EN IEC 60068-2-20 (Juli 2022)

Wieland-Werke AG | Graf-Arco-Straße 36 | 89079 Ulm | Germany
Hotline +49 731 944 1122 | info@wieland.com | wieland.com

07/2024 RP.TMA/Zr