Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 3 Issue 8, August - 2016

A proposal of a new convenient scheme for evaluations of melting shape characteristics of solder materials

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***Abstract*—For the purpose of proposing a new convenient scheme for evaluation of melting shape characteristics of solder materials, melted shapes of some samples of conventional Sn-Pb solder materials and their substitute Pb-free solder materials were numerically evaluated with a digital microscope. A ratio of the maximum height to the peripheral length of the melted solder sample was found to exhibit satisfactory correlation with the conventional spreading ratio value. Thus, this height to peripheral length ratio can be used as a convenient index for indicating and comparing the melting shape characteristics of the conventional Sn-Pb solder materials and their substitute Pb-free solder materials.**

Keywords—Sn-Pb solder; Pb-free solder; Melting characteristics; Numerical evaluation

I. INTRODUCTION

Due to increasing environmental concerns, the conventional Sn-Pb solders are being replaced with various new Pb-free solders. Unfortunately, however, new alternative Pb-free solders usually have higher melting temperatures than the conventional Sn-Pb solders, and are likely to be less easily melted. Therefore, simple substitution of the conventional Sn-Pb solders with any new Pb-free solders is not realistic, and evaluations of melting characteristics of Pb-free solders are required [1].

For the purpose of numerical evaluations and comparisons of melting characteristics (i.e., numerical measurements of melted shapes) of solder materials, evaluation of wettability (i.e., wetting properties) of solder materials have been often conducted. Such evaluations include, for example, measurement of a contact angle or a wetting angle, as well as wetting balance evaluation [2]. Although the wettability analysis is very popular, there are some disadvantages. For example, the principle idea of wetting angles is simple and various manners for their determination are proposed and employed, but actual evaluation procedures may not be so simple. In addition, some specific measurement apparatus sometimes has to be employed.

As another scheme for solder material evaluations, a spread test and related evaluation techniques can be employed. For example, Humpston and Jacobson employed "spread ratio" for evaluation of soldering properties [3]. Specifically, a solder disc was placed onto an underlying plate and then heated to melt and spread. Thereafter, the ratio of the area of solder spread to the original area of the solder disc was calculated as their spread ratio. For example, when the original area of the solder disc was 28 mm^2 and the melted solder covered an area of 280 mm^2, the spread ratio was calculated as ten.

In their study, the original solder disc was prepared from solder foils, while normally solder wires will be available at manufacturing sites. Therefore, this evaluation scheme may not be easily applicable.

As alternative manner, Japanese Industrial Standard (JIS) defines the spreading ratio evaluation technique [4]. With respect to determination of the spreading ratio values (to be described in detail in the next chapter), the exact density value of the solder material to be evaluated is required. When the density value is not available, correct calculations and comparisons of spreading ratio values become difficult.

At actual manufacturing sites, simple comparisons of melting behaviors of solder materials will be beneficial, and convenient scheme for such a purpose is desirable.

Recently, digital microscopes and numerical analysis software to be used for microscope images have become more easily available. Numerical evaluations of the melted shapes of solder samples can be done by means of such a digital microscope as well as appropriate image processing software. Those techniques are applicable to numerical evaluations and comparisons of melting characteristics of various solder materials.

Thus, the authors have tried to conduct numerical evaluations of melted shapes of samples of several solder materials in order to find out any useful and convenient analysis schemes for melting shape characteristics of solder materials.

II. Determination of Spreading Ratio Values of Solder Materials

The spreading ratio value of a melted solder sample is defined as follows:

$$spreading\ ratio\ [\%] = \frac{\mathrm{D-H}}{\mathrm{D}} * 100 \qquad (1)$$

where H is the height of the melted solder sample, and D corresponds to a diameter of a sphere when the solder sample is assumed to have the shape of such a sphere. When a solder sample can be easily melted and spread over the underlying plane, the value H can become smaller, resulting in a larger value of the spreading ratio (close to 100%). On the contrary, when a solder sample is not well melted, the value H becomes larger, which in turn leads to a smaller spreading ratio value.

As an actual calculation process, the volume V [cm^3] of the assumed sphere can be expressed by using the diameter value D [cm] as follows:

$$V\ [cm^3] = \frac{4}{3}\pi * \left(\frac{D}{2}\right)^3 = \frac{\pi}{6}D^3 \qquad (2)$$

This expression can be rewritten into:

$$D\ [cm] = \sqrt[3]{\frac{6}{D}V} = 1.24 * \sqrt[3]{V} \qquad (3)$$

When the values of D and V are expressed in mm and mm^3 instead of cm and cm^3, respectively, the above equation can be as follows:

$$D\ [mm] = 1.24 * \sqrt[3]{V[mm^3] * 10^3} = 12.4\sqrt[3]{V[mm^3]} \qquad (4)$$

When the volume V is to be calculated from the measured mass value M [g] of the solder sample and the density ρ [g/cm^3] of the material, the above equation can be rewritten as:

$$D\ [mm] = 1.24 * \sqrt[3]{{}^{M}/_{\rho}\,[mm^3] * 10^3} = 12.4\sqrt[3]{{}^{M}/_{\rho}} \qquad (5)$$

In the spreading ratio evaluation, when the size of a solder sample is small, accurate and precise measurement of its mass value becomes difficult, resulting in some uncertainty in obtained spreading ratio values. Moreover, when the exact density value of a solder material to be evaluated is not available, the spreading ratio cannot be obtained. Therefore, it will be desirable to establish any other schemes of evaluations and comparisons of the melting characteristics of various solder materials without determination processes of their spreading ratios.

III. Experiment Procedures

A. Solder Materials Evaluated in This Study

The following seven types of commercially purchased solder materials were evaluated. As can be seen, Samples #1 to #4 and #7 are Pb-free solder materials, while Samples #4 to #6 are conventional Sn-Pb solders. Any details in compositions for Samples #1, #2, and #7 are not available.

(1) SnCuNiGe (m.p.=227 °C, 1mmΦ)

(2) SnAgCu (m.p.=217 °C, 0.8mmΦ)

(3) Sn-3Ag-0.5Cu (m.p.=217 °C, 1mmΦ)

(4) Sn50-Pb50 (m.p.=183 °C, 1mmΦ)

(5) Sn60-Pb40 (m.p.=183 °C, 1mmΦ)

(6) Sn63-Pb37 (m.p.=183 °C, 0.8mmΦ)

(7) SnCuNi (m.p.=227 °C, 0.3mmΦ)

Each of those samples had a shape of wire and its diameter was 0.8 or 1 mm, except for Sample #7 which was very thin with 0.3mmΦ. Each of those solder wires was cut into small pieces each having a length of about 1 mm, and used for the measurement procedures to be explained in the next section. For determining the spread ratio values, weight of the respective solder wire pieces after cutting was measured with a digital electric balance.

B. Measurement Procedures

A digital hot plate having a temperature control function was pre-heated up to 260 °C, and kept at that temperature. A square-shape Cu plate with a size of 2 cm x 2 cm was placed on that heated hot plate, and heated about 10 seconds. Then, a solder wire piece in about 1 mm length was placed on the heated Cu plate so that the solder was allowed to melt there. After melted (normally about 10 seconds later), the Cu plate with the melted solder sample on it was removed from the hot plate. For each of the solder materials, the sample number was five. The whole procedures were conducted in uncontrolled laboratory atmosphere.

The square-shape Cu plates were commercially purchased. Before the above-mentioned melting procedures, each of the Cu plate was immersed into rust-and-grease removing liquid (also commercially purchased) as surface pretreatment. No surface observations nor surface roughness measurements of the treated Cu plates were conducted.

After the thus-prepared melted solder samples were well cooled down in laboratory atmosphere, numerical evaluations for their melted shapes were conducted with Keyence 3D Measurement Microscope VR3100. Specifically, shapes of the respective melted solder wire pieces were observed, and the maximum height and the peripheral length of the melted shapes were measured by employing image processing functions of the microscope software.

IV. Results and Discussions

Fig.1 shows the spreading ratio characteristics of the respective melted samples for each of the solder materials tested in this study. The spreading ratio values were calculated from Eq.(1), based on: (1) the maximum height values H of the respective samples that were measured with the microscope; and (2) the values D calculated from Eq.(5) by using the mass values M measured prior to the melting procedures. As the density for the respective solder materials, the typical values available were gathered and used for calculations.

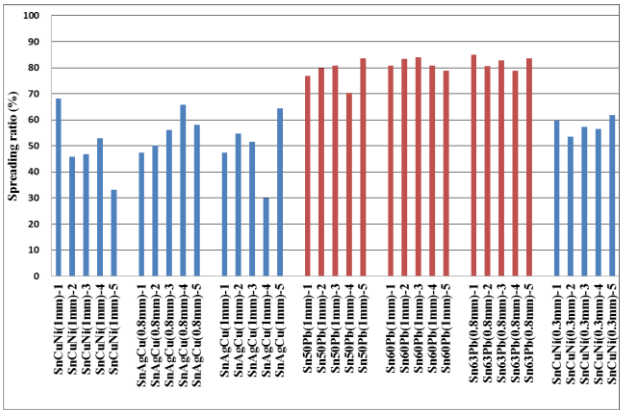

Fig. 1. *Spreading ratio characteristics of the respective melted solder samples.*

In Fig.1, red-color bars indicate the results for the conventional Sn-Pb solder materials, while blue-color bars indicate the results for the Pb-free solder materials. As can be clearly seen, significant differences are recognizable between the results for the conventional Sn-Pb solder materials and those for the substitute Pb-free solders. In Eq.(1), the larger calculated spreading ratio value means the smaller height value of the melted shape of the sample, thus indicating well melted and spread over the underlying Cu plate. Accordingly, the results in Fig.1 clearly indicate that the spreading ratio characteristics can obviously display how well and easily the specific solder materials are melted and spread, as expected.

In order to find out some replacement index for such spreading ratio characteristics, further measurement and evaluations were conducted.

Fig.2 shows the maximum height characteristics of the respective melted samples for each of the solder materials tested in this study. Fig.3 shows relationships between the maximum heights and the spreading ratios of the respective melted solder samples.

When the diameters of the solder wires to be compared with each other are in the similar range, differences between the Sn-Pb and Pb-free solder materials are recognizable in the maximum height characteristics. However, for the solder wire samples with a different diameter range (i.e., the SnCuNi sample with a diameter of 0.3 mm), the maximum height characteristics are not suitable indicators.

Fig.4 shows the peripheral length characteristics of the respective melted samples for each of the solder materials tested in this study. Certain differences between the conventional Sn-Pb solder samples and the Pb-free solder samples are found. However, there is again the possibility that differences in sizes of solder samples to be compared (in this case, the diameters of the solder wires) have certain undesirable influences in comparison results.

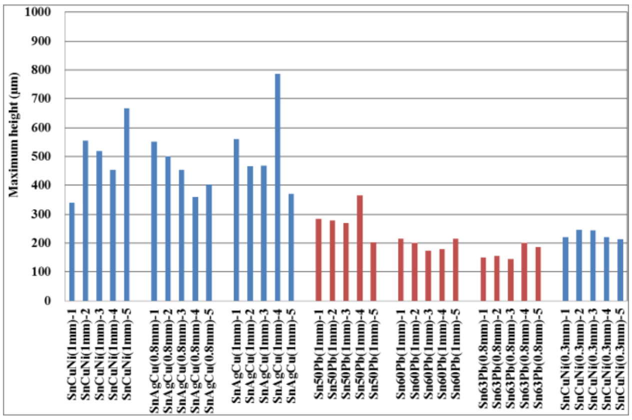

Fig. 2. *Maximum height characteristics of the respective melted solder samples.*

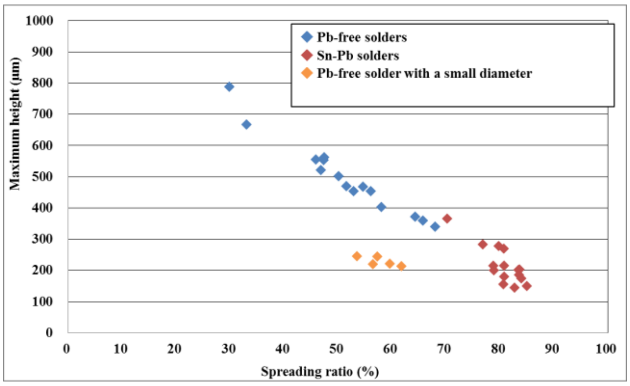

Fig. 3. *Relationships between the maximum heights and the spreading ratios of the respective melted solder samples.*

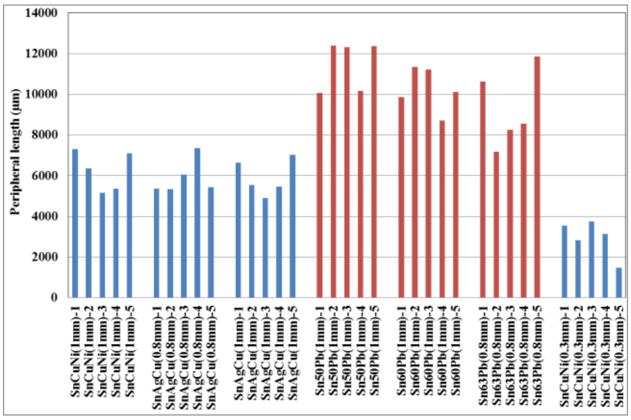

Fig. 4. *Peripheral length characteristics of the respective melted solder samples.*

Then, Fig.5 shows relationships between the maximum heights and the peripheral lengths of the respective melted solder samples. The results indicate that there are certain clear differences in the characteristics between the Sn-Pb solders and the Pb-free solders.

Thus, as the further alternatives, a ratio of the maximum height to the peripheral length was calculated for each of the solder materials tested in this study, and the results are shown in Fig.6.

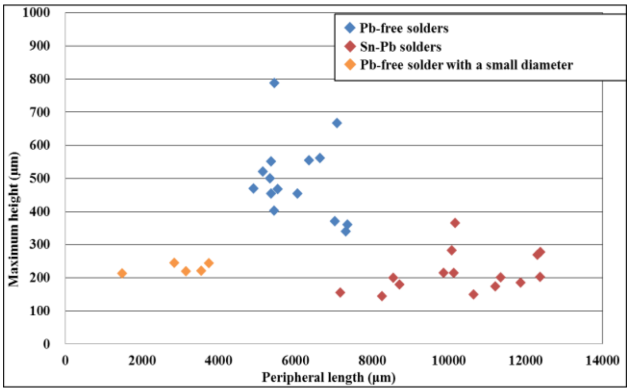

Fig. 5. *Relationships between the maximum heights and the peripheral lengths of the respective melted solder samples.*

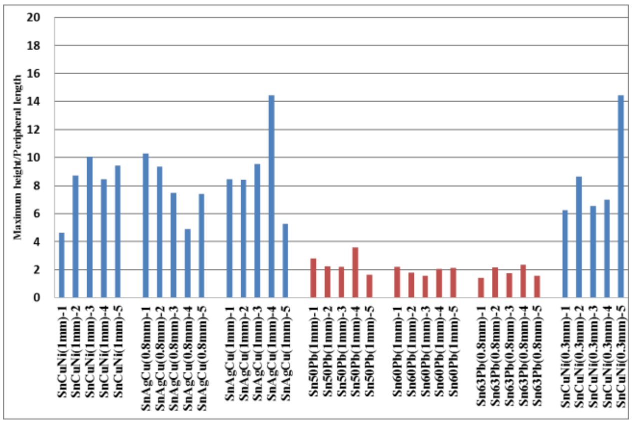

Fig. 6. *Ratios of the maximum heights to the peripheral lengths of the respective melted solder samples.*

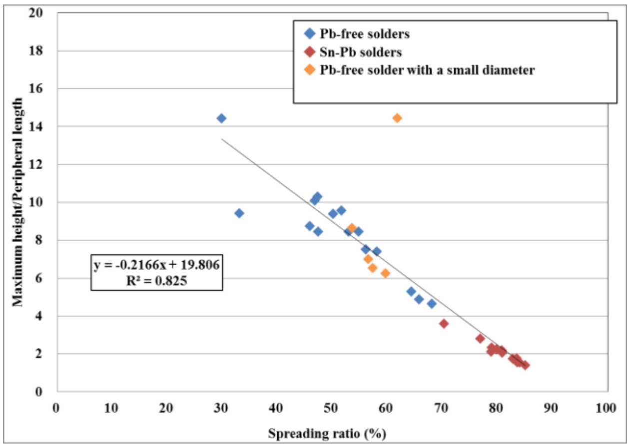

Fig. 7. *Relationships between the ratios of the maximum heights to the peripheral lengths and the spreading ratios of the respective melted solder samples.*

The obtained characteristics shown here indicate that irrespective of differences in the sample sizes, the conventional Sn-Pb solder samples and the Pb-free solder samples are distinguishable from each other.

Fig. 7 shows the relationships between the ratios of the maximum heights to the peripheral lengths and the spreading ratios of the respective melted solder samples. Although some fluctuations exist, both values basically show relatively satisfactory correlations. As a result, the ratios of the maximum heights to the peripheral lengths were found to be usable as replacement of the conventional spreading ratio characteristics.

Since digital microscopes and numerical analysis software to be used for microscope images have become more easily available, measurements of the maximum height as well as the peripheral length of a melted shape of solder samples will not be difficult, even at manufacturing sites. Therefore, evaluations and comparisons of melted shape characteristics of several solder materials by means of the maximum heights to peripheral length ratio can be convenient substitute to the conventional spreading ratio analysis.

V. Conclusions

For the purpose of proposing a new convenient scheme for evaluations and comparisons of melting shape characteristics among several solder materials, melted shapes of some conventional Sn-Pb solder materials and substitute Pb-free solder materials were observed and numerically evaluated with a digital microscope. A ratio of the maximum height to the peripheral length of the melted solder sample was found to exhibit satisfactory correlation with the conventional spreading ratio value. Thus, this height over peripheral length ratio can be used as a convenient index indicating and comparing the melting shape characteristics of the conventional Sn-Pb solder materials and their substitute Pb-free solder materials.

It should be noted that, in this paper, focus was placed onto any possible new convenient schemes applicable for analysis and comparisons of melted shape characteristics of solder materials. Actual further investigations on differences in melting characteristics of several solder materials should be done by employing the proposed evaluation scheme.

References

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