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Liquid Braze Surface Tension Determination Algorithms Implemented in Brazeability Analysing System

1. Introduction

The results of the research on electronic and electric devices production, consumption and waste conducted in European Union estimates the production of electronic and electric waste per one citizen during a year on about 23 kg. Assuming that in Europe live approximately 350 millions of people, there is 8.05 millions tons this kind of waste yearly. It can be observed the production and consumption trend is ascending, so in 2012, the consumption can exceed 12 millions tons. Therefore, the European Parliament declares two direc-tives:

- RoHS – concerning on limited usage of materials, that are negative affecting on natural environment, but are currently used for producing electrical and electronic devices [1],
- WEEE – concerning on used electrical and electronic devices [2].

The basis for taking these actions was the elimination of lead from the production process. From above 50 years, the electronic industry was using soldering with pure or near eutectic tin-lead solders, as the materials in joining technology. They have unique physic-chemical properties – low melting temperature 183–190 °C, good availability and beneficial economic price. Lead, cadmium, nickel belong to the neurotoxin group [3] – especially lead causes permanent brain damage, braking the neurons connections, what results the lack of thinking efficiency and psyche changes.

The directive RoHS is ruling in Poland since 27.03.2007 based on the Economy and Labour Minister regulation (No 69, pos. 457). The introduction of this directive caused large changes in electronic elements production processes, the need of new solders, fluxes and dedicated technologies research to achieve the production of joins with appropriate good properties.

Nowadays, there exist two ways of research – new materials and joining technologies and new automatic measurement methods of joining process properties. In the first group, the main research is concerned on alternative solders towards SnPb. Nowadays, there are

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used in the industry substitute alloys: SnAg, SnCu, SnAgCu. They have higher melting temperature than SnPb: Sn99 Cu0,7 (227 °C), SnAg3 Cu0,5 (219 °C), and also higher value of surface tension, what causes the aggravation of brazing process execution. The second research area is concerned on the new automatic measurement methods of brazeability and surface tension parameters. The obtainment of quantitative results allows to compare the physic-chemical properties of examined solders, as well as to check the cross-phase effects of appropriate materials.

In the Computer Engineering Department, Technical University of Łódź, the automatic system for determining brazeability and surface tension parameters of fluid metals, was developed. The research was carried out from 2002 till 2004 under the Polish Research Committee grant no 4 T10C 040 22 – *Model of automated brazeability tester for industrial purposes* [4].

2. Surface tension measurement methods implemented in Brazeability Analysing System

Surface tension is the thermodynamic property, which defines the amount of executed work to increase the fluid surface. The generation of fluid braze surface tension is the result of molecular interactions of three phases: fluid, solid and gas (Fig. 1). The calculation of fluid braze surface tension is the function of accepted measurement method, and also the process conditions. The experiments proved, that the surface tension value decreases with temperature increase.

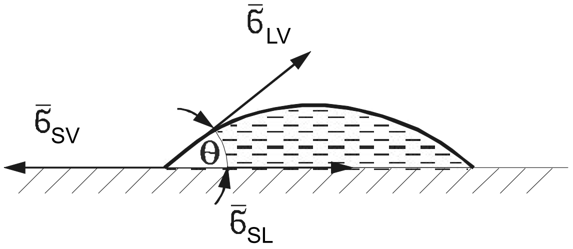

Fig. 1. Physic-chemical parameters of the specimen

The state of equilibrium for system from Figure 1 is defined by Young formulae:

$$|\bar{\sigma}_{LV}|\cos\theta+|\bar{\sigma}_{SL}|-|\bar{\sigma}_{SV}|=0 \tag{1}$$

where:

θ – wetting angle,
σ_{SV} – surface tension on the solid – gas boundary,
σ_{SL} – surface tension on solid – fluid boundary,
σ_{LV} – surface tension on fluid – gas boundary.

The Brazeability Analyzing System offers two methods of liquid braze surface tension determination:

- maximum pressure in gas bubble method,
- plate method.

The experiment for determining liquid metal surface tension with the use of the maximum gas bubble pressure is based on sinking the pipe in liquid metal on appropriate depth h. During the experiment, there flows the gas delivered from outside controlled system to the pipe, the bubble on the end of the pipe is formed and the pressure in newly formed bubble is registered. The process of gas bubble forming and hypothetical pressure is shown in Figure 2. The points A and B respond to sweep gas pressure increase, what results of bubble forming. The shape of gas bubble and the value of registered pressure depend on the wettability of pipe by fluid metal. At point C, the pressure achieves the maximum and the bubble has semicircular shape, which radius is equal to the geometrical radius of pipe. At point D and E, the pressure de-creases and the radius of bubble curvature is still growing. Finally, the bubble is released from the pipe and the cycle is repeated.

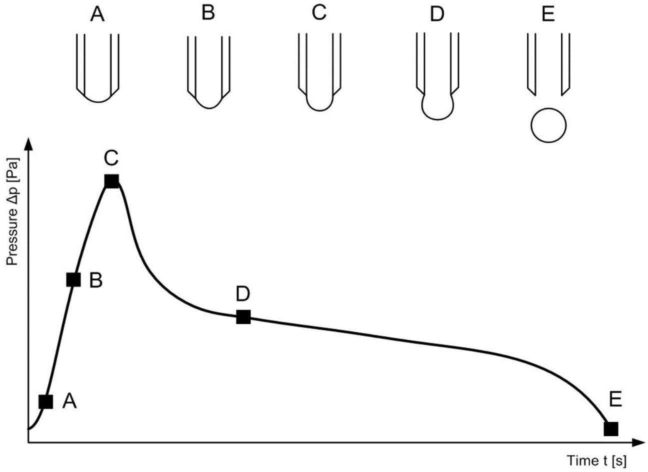

Fig. 2. The stages of bubble forming process and corresponding hypothetical pressure

The calculation of surface tension can be conducted basing on the following formulae:

$$\sigma = 0.5 \cdot r \cdot \Delta p \tag{2}$$

where:

σ – measured surface tension,

R – radius of the pipe,

Δp – the difference between the gas flowing through the pipe and the hydrostatic braze pressure, which is needed to abrupt the bubble from the pipe.

The experiment for determining surface tension using plate method is based on sinking the flat specimen made from non-wetting material in fluid braze. The value of registered force acting on plate depends on sinking in fluid braze depth, specimen's perimeter and surface tension. In point B, the contact of specimen with fluid braze is registered. In the range between points B – C – D, the wetting angle is changing from 0 to 180^o. The outpass of critical depth E (the level equals surface tension), the force acting on specimen is proportional to the sinking depth. The point E, where the curve shape is changing to a line (turning point), is the value of braze surface tension. At the point F, the process of specimen sinking in fluid braze is to end (Fig. 3).

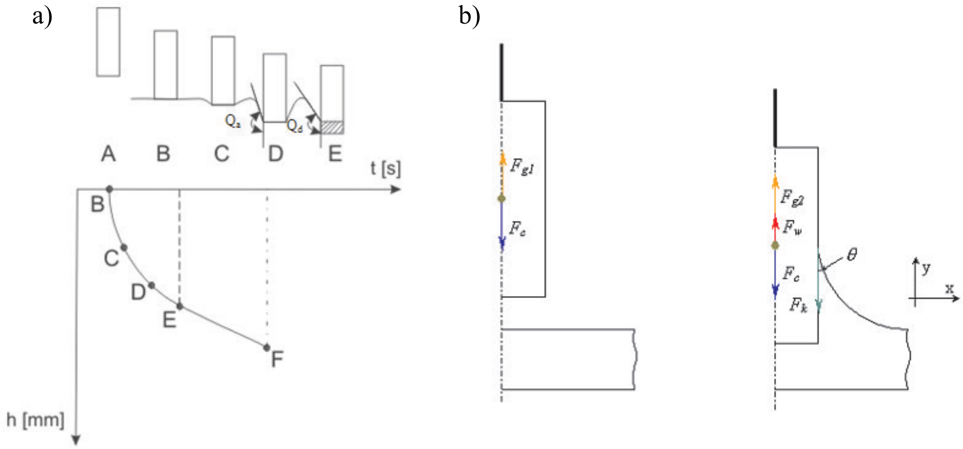

Fig. 3. The specimen immerse in fluid braze (without wetting) (a); forces acting on vertical plate (surface wetting) (b)

Determining the surface and cross-phase tension is carried out in the case, when the projections sum of all acting on *OY* axis forces is equal:

$$\sum_{i=1}^{i=n} F_{iy} = F_{g2} + F_w - F_c - F_k = 0 \tag{3}$$

where:

F_{g1} – force registered by measurement system before immerse, directed upward,
F_c – gravitation force, directed downward,
F_{g2} – force registered by measurement system after sinking, directed upward, $F_{g2} > F_{g1}$,
F_w – buoyancy force, directed upward,
F_k – capillary wetting force.

The knowledge of adhesive tension F_k and wetting angle $\theta = 180^o$ (used Al_2O_3 material is non-wettable by most fluid metals) allows calculating surface tension of fluid braze:

$$F_k = O_p \sigma_{LV} \cos\theta \tag{4}$$

where:

O_p – specimen's perimeter,
σ_{LV} – fuid surface tension on fluid – gas boundary,
θ – wetting angle.

3. System for automatic surface tension determination and analysis

In Computer Engineering Department, the automated measurement systems allowing to determine surface tension, were developed (Polish Research Committee grants: 4 T10C 040 22 – *Model of automated brazeability tester for industrial purposes* and 8 T10C 005 14 – *Automated measurements of surface tension and wetting angles in high temperature*) [4]. Both systems are computerized and allow for carrying out the measurement experiments' series and the analysis of registered process parameters. The first research was focused on i.a. implementation of maximum bubble pressure method in automated device, while the second uses the laying drop observation method.

The surface tension analyzing system is a group of devices controlled by computer system. The cooperation of devices allows for carrying out the measurement experiment along previously described methodology. The Figure 4 shows the configuration of measurement system. The experiment process starts with environment stabilization, when the gas protective atmosphere is activated and the working temperature is set to value over braze melting temperature. Then the pipe connected to external gas system is sinking in fluid braze on appropriate depth. The pressure in external gas system is increased, what starts the bubble forming process. While the bubble is growing, the pressure is observed by the system. Pressure slope occurs when the bubble is released. The experiment sequence diagram is shown in Figure 5.

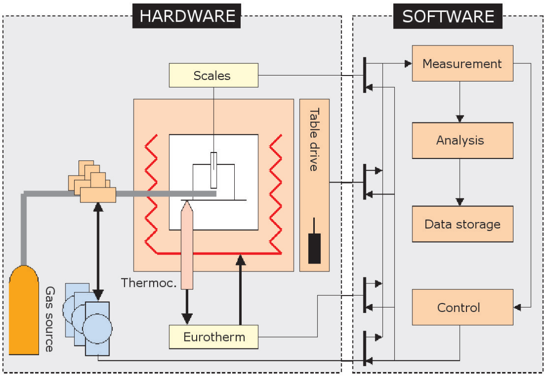

Fig. 4. Configuration of measurement system (hardware components: scales, table driver, Eurotherm – furnace controller, gas system – source and controllers, software tasks: measurement, analysis, data storage and process control) [4]

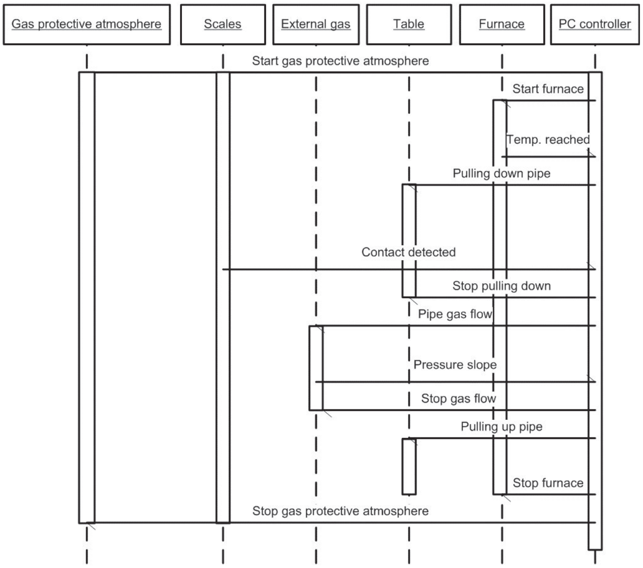

Fig. 5. Experiment sequence diagram

The verification of implemented algorithms was carried out through the experiments series, which results are presented in Figure 6 and Figure 7:

- results of bubble maximum pressure method experiments (o),
- results of plate method experiments (□).

In Figure 6, the results of experiments carried out in appropriate constant temperature for Sn60Pb40 and lead free SnAg3,5 braze materials are presented. It can be conducted, that the mean value of surface tension in 250 ^{o}C for Sn60Pb40 is 489 mN/m and for SnAg3,5 504 mN/m.

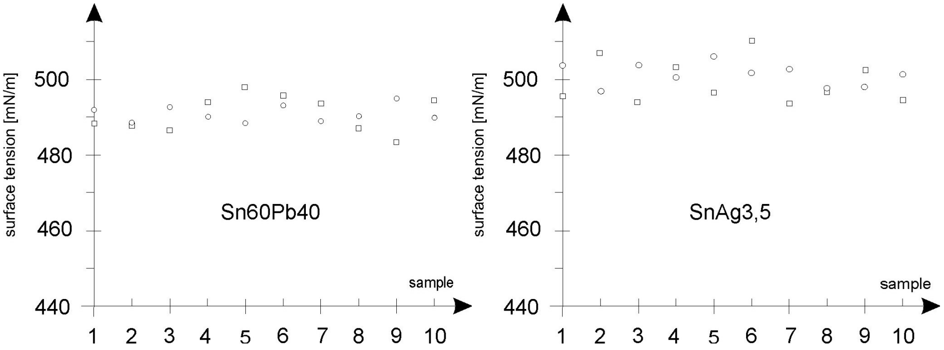

Fig. 6. Surface tension measurements for Sn60Pb40 and lead free SnAg3,5 braze materials in 250 ^{o}C

In Figure 7, the results of surface tension measurements for Sn60Pb40 in range 200–700 °C and for SnAg3,5 in range 250–900 °C are presented as changes of above mentioned parameter in function of temperature.

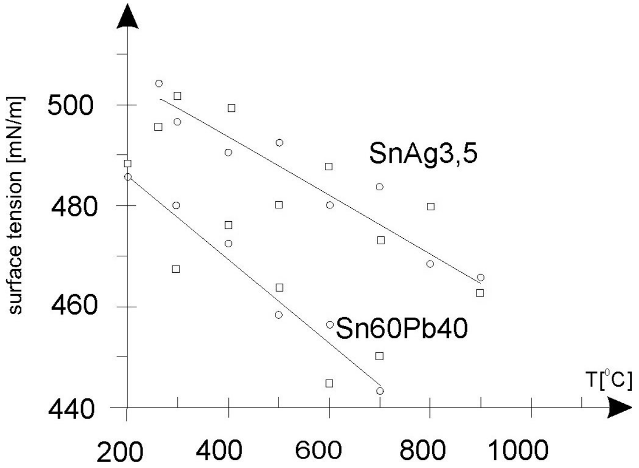

Fig. 7. Surface tension measurements for Sn60Pb40 and lead free SnAg3,5 braze materials in function of temperature

4. Conclusions

The verification procedure of applied in Brazeability Analysing System plate method algorithm has proved its correctness in calculations of brazeability in wide range of temperatures up to 1000 °C. The advantage of this algorithm and its implementation is the repeatability consequent on full automation of the measurement process. Calculated parameters allow matching best braze / solder for appropriate specimen material, flux or gas protective atmosphere for appropriate set brazed- and brazing material. The results assert the possibility of using described methods for determination of selected brazeability parameters in high temperatures. The plate method is applicable for determination and optimalization of brazing process parameters for appropriate set of braze and base material. Therefore, the research on new brazeability automation measurement algorithms to achieve quantity results is most purposeful.

References

[1] *Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)*. Official Journal of the European Union, L37/19, 2003.

[2] *Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on the waste electrical and electronic equipment (WEEE)*. Official Journal of the European Union, L37/24, 2003.

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[4] Sankowski D., Senkara J. i in., *Projekt badawczy KBN nr 4 T10C 040 22 pt. „Model automatycznego testera pomiaru lutowności lutów twardych dla zastosowań przemysłowych”*. Łódź, 2002.