Micro-scratching tests of a lead-free solder alloy SAC 305 used in electronic industry

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Abstract. The electronic connections need to satisfy three functionalities and those are the electrical, thermal and mechanical functionalities. The PCB (Printed Circuit Board) has the role of providing a mechanical support for an assembly of various electrical and electronic components and to connect them to obtain a functional end-product. The goal of the present paper was to identify the mechanical and tribological properties of the lead-free soldering alloy SAC 305 deposit on the copper-PCB assembly used in electronic technology. The variation of the friction coefficient for all the normal forces applied on the test samples was analyzed. The understanding of the behavior of the lead-free soldering alloy for the micro scratch test is essential for the improvement of the hole electronic system integrity.

1. Introduction

A printed circuit board (PCB) serves to mechanically support and electrically connect a set of electrical and electronic components. [1]

The mechanical function provides the mechanical integrity and the resistance of the electronic assembly. The role of the soldering alloys is to interconnect the electrical and electronic components usually by surface mount technology (SMT). They also serve as a mechanical support, holding the component in position on the PCB. [2, 3]

The environmental aspects have determined the replacement of the lead based soldering alloys with lead-free solder alloys in the electronic industry. A very important aspect in the use of the lead-free solders is to ensure at least the same quality and reliability for the electrical connection as the as the classical lead-based soldering alloys. [4]

The objective of the paper was to observe the mechanical and tribological characteristics of the soldering alloy SAC 305 deposited on the FR4 rigid support covered with a copper layer. The SAC 305 is a lead-free soldering alloy and has the following composition: 96.5% Sn, 3.0% Ag, 0.5% Cu.

The FR4 rigid support is made of a woven glass fabric with epoxy resin system. This objective is accomplished through the scratch testing method.

We can see from the profilogram that the material deforms in the proximity of the path of the indenter, where borders of materials are created. This behavior leads to the idea that the material is ductile.

The scratch test is a common testing procedure that provides fast results for the critical loads in relation to the adhesion properties of coatings. It is related to the measurement of the amount of plastic deformation caused by the indenter penetration. The scratch testing procedure involves the use of an indenter or a scratching blade in the vertical plane, generating the loading force, and in the horizontal
2. Experiment
The objective of the experiment was to determine the mechanical and tribological properties of the SAC 305 soldering alloy deposited on the copper substrate which covers the FR4 rigid support.

The micro-scratching tests have been conducted on a Scratch-Testers Millennium 100 equipment, which performs scratches on the samples and provides as results the value of the normal force, the friction force and the friction coefficient.

The profilogram of the surface after the tests was determined with a Leica 3D Dual Core equipment, which allows the identification of the penetration depth of the indenter.

During the experiments a single type of sample has been tested, which is composed of a SAC 305 soldering alloy deposited on a FR4 rigid support with a copper substrate. The sample can be seen in Figure 1.

A Rockwell indenter with a diamond tip with a radius of 50 μm was used to apply the normal loading force, which was kept constant during the tests.

A series of 6 scratches have been made with a length of 1.1 mm. The normal loading force was increased from 10 N for the first scratch to 20 N, 30 N, 40 N, 50 N and respectively 60 N for the last scratch.

3. Results and discussion
For the 10 N normal force, the indenter moves with a speed of 0.167 mm/s over a distance of 1.1 mm for 6.587 s. The profilogram of the scratch groove can be seen in figure 2.
When the normal force was changed to 20 N, 30 N, 40 N, 50 N and 60 N, the indenter moved with a speed of 0.167 mm/s over a distance of 1.1 mm for 6.587 s. The profilograms of the scratch grooves can be observed in figure 3 (20 N), figure 4 (30 N), figure 5 (40 N), figure 6 (50 N) and figure 7 (60 N).

In the profilograms we can observe that for ductile materials the borders formed on each side of the scratch are not symmetrical. This behaviour was observed in other similar studies.

The tests were made at room temperature 25°C.
The variation of the friction force for all the six normal forces applied function of the scratch length is shown in figure 8.a, while figure 8.b presents the variation of the mean friction coefficients depending on the all six normal forces applied.
After the optical inspection and after the analysis of the profilograms, it can be concluded that the indenter did not pass through the soldering alloy SAC 305 layer, so it does not penetrate the copper layer.

The scratch groove depth for all the six normal loading forces can be observed in table 1.

**Table 1. Depth of the scratch groove**

| Normal Force [N] | Scratch groove depth [m] |
|------------------|--------------------------|
| 10               | 28.6                     |
| 20               | 50.2                     |
| 30               | 52.7                     |
| 40               | 51.3                     |
| 50               | 52.8                     |
| 60               | 67.2                     |

4. Conclusions
The indenter does not penetrate through the hole soldering alloy layer to reach the copper substrate deposited on the FR4 rigid support, regardless of the applied normal loading force used in the current tests.

By inspecting the profilograms it can be observed that after the micro-scratching process, the soldering alloy suffers plastic deformation. A border of material can be seen on each side of the scratch groove made by the indenter on the surface of the soldering alloy, which leads to the conclusion that the material has a ductile behaviour. The removed material is loosened by the micro-scratching process.

Some regions of the detached coating have been observed along both sides of the groove produced by the elastic recovery behind the indenter and plastic deformation in substrate.

The average friction coefficient is not influenced by the normal force applied and it is relatively constant with values between 0.34 and 0.37.

From the mechanical point of view, it is preferred for the material used for the electronic connection to have a ductile behaviour in order to take some of the elastic deformations created by the mechanical strains. A brittle connection should be avoided because it has a lower reliability.
The goal of the paper was to determine the profile of surfaces subjected to micro-scratch tests, in order to identify if the SAC305 soldering alloy is ductile or brittle, this goal being attained. The results obtained from these tests can help in future studies for the assessment of the way a scratch or an imperfection of the contact surface can influence the electrical characteristics of the electronic systems. We can also observe from the profilograms that both sides of the scratch are asymmetrical. The removed material increases the volume in the process of dumping. Electronic packaging integrity depends on the mechanical integrity of the soldered interconnects.

5. References
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Acknowledgments
"This work was funded by the Austrian COMET-Program (Project K2 XTribology, Grant No. 849109) and has been carried out within the Excellence Centre of Tribology. The authors would like to thank professor Franek Friedrich for his support and would also want to thank to Tetyana Khmelevska".