Structure of Ball Grid Array/Permanent Semi-Elastomeric Thermally Conductive Crumb Rubber Reinforced Bituminous Stencil/Printed Circuit Board Interconnects

P. Karydopoulos, P. Frantzis, *Eur Ing CEng MIMechE*, and N. Karagiannis

Abstract **– An investigation is reported into the structure of Ball Grid Array/Permanent Stencil/Printed Circuit Board interconnects produced when semi-elastomeric bituminous stencils are formed or placed within standard interconnects. Such interconnects have the potential to extend the service life of Printed Circuit Boards especially for use in aviation, shipping and military applications.**

Keywords **– BGA, PCB, Interconnects, Bituminous permanent stencils, Crumb rubber**

INTRODUCTION

The BGA (Ball Grid Array) is an electronic device that consists of copper pads (situated at the bottom side and that are) arranged in a grid manner onto which micro-balls (made from solder) are soldered, hence the name. On the PCB (Printed Circuit Board), onto which the BGA balls are resoldered, there is a matching set of copper lands. The BGA packages offer many advantages over other packages and as a result they are increasingly used for the manufacture of electronic circuits. BGAs are currently used extensively in mobile phones, computers, modems, handheld devices, office environment equipment, trucks and busses, and in aviation, shipping and military applications. A faulty BGA component is reworked, i.e. removed from the PCB, cleared of the balls, cleaned and reballed by soldering a new set of matching balls onto the pads of the BGA.

This research/article/study has been co-financed by the European Union and Greece - Operational Program 'Human Resources Development' - NSFR 2007-2013 - European Social Fund (General Secretariat for Research and Technology).

First Author Panagiotis Karydopoulos is with Computer Systems, Didimotixou 29, Neapolis, 56727 Thessaloniki, Greece (phone: +2310672799; e-mail: karydopoulos@computer-systems.gr).
Corresponding Second Author Panagiotis Frantzis is with Computer Systems, Didimotixou 29, Neapolis, 56727 Thessaloniki, Greece (phone: +2310672799; e-mail: frantzis@computer-systems.gr).
Third Author Nikolaos Karagiannis is with Computer Systems, Didimotixou 29, Neapolis, 56727 Thessaloniki, Greece (phone: +2310672799; e-mail: info@computer-systems.gr).

The resoldering process was carried out using a rework station and a permanent BGA stencil that was placed between the BGA and the PCB [1]-[3]. Alternatively, the stencil was formed by casting at the end of the resoldering process by the gravity-assisted liquid-stencil infiltration into the interstice of the BGA/PCB interconnect [4].

A BGA permanent stencil is a perforated membrane (of thickness between 0.3-0.4 mm) which consists of arrays of perforations (micro-holes or apertures) arranged in a grid manner, i.e. a mirror image of the pads and lands patterns. The membrane is made from a semi-elastomeric material that in turn is made by mixing a bituminous emulsion binder, conductive filler and water treated crumb rubber powder. The stencil is produced from the membrane by laser cutting and drilling and requires no cleaning processes. The stencil could be made to reduce the temperature of the BGA by transferring heat from the joints to the heat-sink system by monitoring the thermal conductivity of the material of the stencil. The material could therefore include up to 67% by weight of the neat binder of commercially available thermally conductive filler to enhance the thermal conductivity of the stencil. The stencil could also include up to 43% by weight of the neat binder of commercially available crumb rubber powder reinforcement produced from discarded car/truck tyres to increase the toughness. The stencil has the ability to render the use of corner/edge adhesives unnecessary. Adhesives are currently being used in the electronics manufacturing industry to act as BGA mechanical/thermal shock absorbers due to dropping/heating and to absorb flex due to PCB warping, and to inhibit whisker formation/growth by surrounding the solder joints [1]. The stencil, in addition, has the potential to inhibit whiskers formation and growth in the solder joints by surrounding and continuously compressing the joints [1]-[4]. The stencil can also act as a coating to prevent or at least minimize degradation of the interconnect by preventing corrosion. This is the first time that such materials are being used in highly sensitive electronic hardware applications.

EXPERIMENTAL

Materials

The commercially available semi-elastomeric materials were made from a 1-component cold-setting bituminous emulsion binder. The filler was a thermally conductive fine powder. The crumb rubber powder (produced by an ambient grinding process) was from car tyres (synthetic rubber) of 0-0.2 mm (200 μm maximum, 60 mesh) particle size.

Methods

The crumb rubber powder was treated using the water activated method prior to mixing to enhance the binder /rubber/filler bond [1]. The binder was mixed with various amounts of conductive filler and crumb rubber powder. The mixtures were laid up on a flat surface. The flat surface was first cleaned and then coated with a thin layer of release agent (paste wax). It is claimed that the membranes produced were made from a semi-elastomeric material in the sense that they are able to fold over their side without any visual cracking [3]. In laboratory rework trial tests, BGA components were reballed using flux [1], [3]. Then, they were resoldered to a PCB in an infrared rework station using flux that also involved the use of a stencil that was placed between the BGA and the PCB [3]. Factory produced BGA/PCB interconnects were modified by casting.

Typical interconnects were split open using a hammer and chisel to produce cuts for structure examination [4]. The stencil-reworked PCBs were next put into the production line and their long-term functionality is continuously monitored.

RESULTS AND DISCUSSION

Fig. 1(a) shows a typical (laser cut/drilled) stencil (cross-sectional area 34x34 mm^2, 0.35 mm thickness and 0.6 mm aperture) and Fig. 1(b) a typical reworked BGA/Stencil/PCB interconnect.

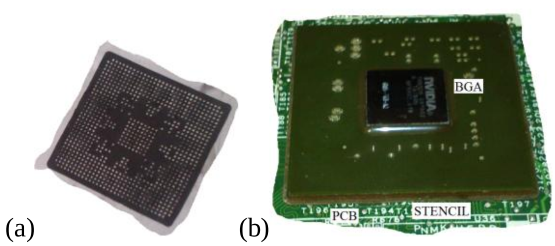

Fig. 1. Typical stencil (a) and typical reworked interconnect showing the BGA on top of the stencil (b).

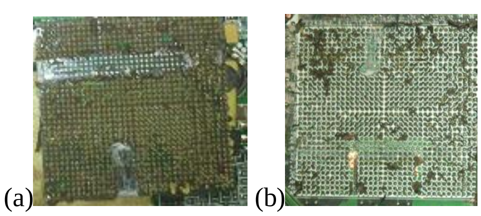

Fig. 2. Typical cut from factory produced BGA/Stencil/PCB interconnect showing cross-sections covered with the material formed by casting on the BGA side (a) and on the PCB side (b).

Fig. 2 is a typical cut from a factory produced BGA/Stencil/PCB interconnect that shows cross-sections covered with the material formed by casting, on the BGA side (a) and on the PCB side (b). Fig. 3 is a typical cut from a laboratory produced BGA/Stencil/PCB interconnect made using flux and an infrared rework station that shows cross-sections covered with the (laser cut/drilled) stencil, on the BGA side (a) and on the PCB side (b).

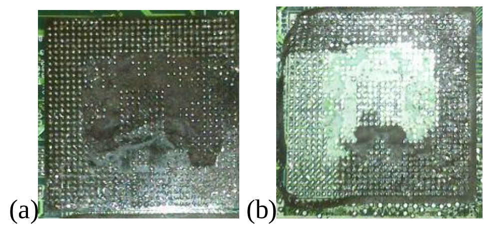

Fig. 3. Typical cut from a home produced BGA/Stencil/PCB interconnect showing cross-sections covered with the stencil on the BGA side (a) and on the PCB side (b).

Fig. 2 and Fig. 3 show the structure of BGA/Stencil/PCB interconnects and confirm the functions of the stencil which are (i) to surround and hold the micro-balls firmly within its apertures, (ii) it has the potential to inhibit whiskers formation and growth in the solder joints by applying a continuous compressive stress via the semi-elastomeric stencil to the joints [4], (iii) its good adhesion and robustness i.e. the material appears to be compact, and (iv) its natural ability to absorb flex due to PCB warping and mechanical shock due to dropping thus rendering the use of corner/edge adhesives unnecessary [4]. The stencils were found to adhere well to both the BGA and the PCB surfaces and therefore they can also act as a protective coating preventing degradation of the interconnects by preventing corrosion. Preliminary water diffusion tests [5], [6] indicated that the material absorbed no water at any time, contrary to resins [7]-[9]. Most metals corrode with time (i.e. recombine with corrosive agents in the environment like oxygen, chlorine, sulphur, fluorine etc.) in an attempt to return to their natural state. Since these corrosion products interfere with the passage of electrical current across an interconnect, then the contact surfaces can be coated over to prevent or at least minimize the formation of corrosion products [10].

The method of measurement of the thermal conductivity (K) of the material developed in previous work [3]-[4] yielded a similar range of values of the thermal conductivity of the material of the stencil developed in this work and showed a material with considerable increase in K suitable for use in electronic applications.

The cost of commercially available conductive powders is high and therefore a new thermally conductive material was developed, namely K5 PRO, that is a viscous paste designed to give a high thermal conductivity at a very low cost and can be used when the thermal conductivity of a bituminous stencil is low or on top of a component on a PCB to aid to the cooling process. The method of measuring the thermal conductivity of thin solid samples of the materials developed in the previous work [3] was used. When the material to be measured is a non-solid, then a sample of this material is sandwiched between two copper plates (dimensions 32x25 mm^2 and 0.62 mm thickness) to form the specimen and is shown in Fig. 4. The specimen was then placed in front of the gun mouth of a Soldering Heating Station and at a distance of 10 mm, as shown in Fig. 5. The gun mouth (dimensions 12x12 mm^2) was set to give out a constant jet/flow of hot air at 90°C. Next, the heater was turned on and measurements of the temperatures at the centre of the area A, T_2 (the face of the specimen next to the mouth) and T_1 (outer surface), were taken after 5 minutes (to allow for a steady-state of heat transfer, Q, to be reached) and at a 1 minute intervals, using an IR Thermometer (Fig. 5). The stiff sticky K5 PRO material adheres well to both copper plate surfaces making the measurements of T_1 and T_2 accurate enough. Then, the thermal conductivity of the sample could be given by the following Equation (1)

$$Q/A = K\,(\Delta T/t) \qquad (1)$$

where K is the value of the thermal conductivity of the K5 PRO sample, $\Delta T = T_2 - T_1$ and t is the thickness of the sample (0.7 mm). The value of Q was taken to be 600 W [3]. Note that the area A in Equation (1) was taken to be 12x12 mm^2, i.e. the dimensions of the mouth of the gun.

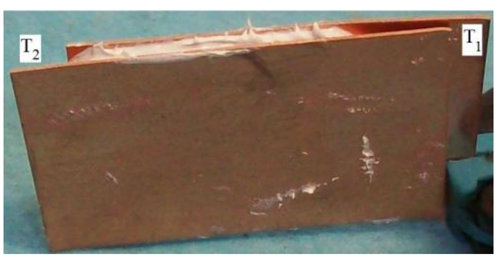

Fig. 4. Specimen used to measure the thermal conductivity of a sample (shown in white) of a non-solid material sandwiched between two copper plates.

To establish the new method of calculating K in air, various samples of known K were used that were in the form of thin squared plates (dimensions 25x25 mm^2) from copper (K = 400 W/m C and thickness t = 0.14 mm), aluminium (K = 250 W/m C, t = 0.53 mm), steel (K = 16 W/m C, t = 0.45 mm), thermally conductive pad (K = 1.7 W/m C, t = 0.3 mm), and glass (K = 1.05 W/m C, t = 0.58 mm). Next, a graphical technique to account for the total heat losses was developed that was a plot of the experimentally obtained values *Kexp*, using Equation (1), against the actual K values for low range of K values [3], Fig. 6. The experimental procedure was repeated using specimens. Typical data are shown in Table 1 and *Kexp* for K5 PRO was calculated to be

$$Kexp = 0.2486 \times 10^3 \text{ W/m C}$$

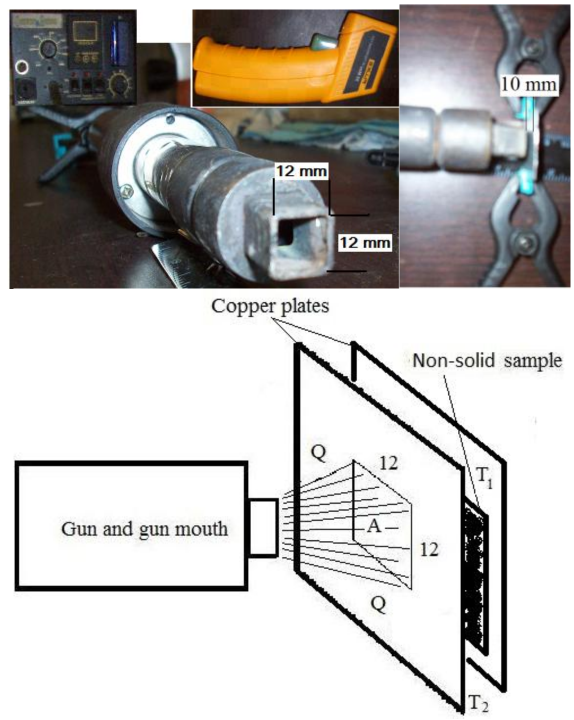

Fig. 5. Soldering Heating Station Gun and IR Thermometer (shown in orange) and set-up showing the specimen.

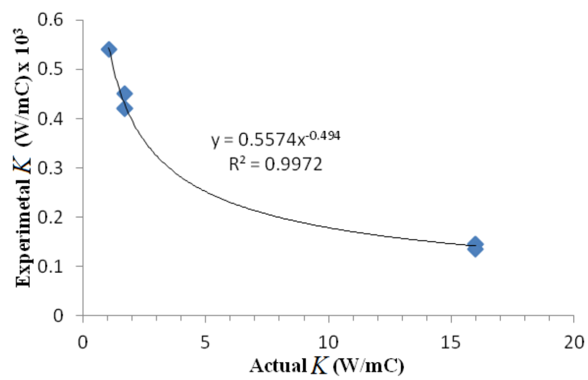

Fig. 6. Experimental K against actual K for low K values.

TABLE 1: TYPICAL DATA OBTAINED.

T2	***T1***	***ΔT***
56.4	45.4	11.0
57.8	45.8	12.0
59.0	47.2	11.8
60.8	48.4	12.4
		Average ΔT = 11.8

From Fig. 6 an empirical relationship was derived as follows

$$Kexp = 0.5574\,K^{-0.494}$$

and K can therefore be calculated from Equation (2) below

$$K = 0.311\,(1/Kexp)^2 \qquad (2)$$

Hence, an average value of K = 5.03 W/m C could be estimated for the K5 PRO material. To examine and establish the validity and repeatability of the method, specimens consisting of copper plate/EHT heat transfer compound/copper plate (dimension of copper plates 32x25 mm^2 and thickness of compound layer t = 1.2 mm) were made to measure and confirm the thermal conductivity of the commercially available compound (0.9 W/m C). An average value of K = 0.76 W/m C could be calculated from Equation (2) which is a close enough approximation.

Finally, it was reported previously [3], [4] that faulty BGA components found on PCBs contained within customer Laptops and PCs were reballed and then reworked using a latex emulsion type of permanent stencils. The long-term functionality of the stencil-reworked PCBs in the production line was continuously monitored by monitoring the number of customer Laptops and PCs that were returned with faulty stencil-reworked BGAs.

TABLE 2: APPRAISAL OF STENCIL-REWORKED LAPTOPS & PCS WITHIN A PERIOD OF 8 MONTHS.

Total number of Laptops & PCs repaired	2,500
Total number of stencil-reworked Laptops & PCs	188
Total number of stencil-reworked Laptops & PCs malfunctioned	22
Total number of stencil-reworked Laptops & PCs delivered to customers	166
Total number of stencil-reworked Laptops & PCs returned from customers	25
Total number of stencil-reworked Laptops & PCs malfunctioned	6
Total number of stencil-reworked Laptops & PCs returned to customers	160
Total number of control stencil-reworked Laptop malfunctions	0

Factory PCBs that contain BGAs modified by casting were fitted into a home Laptop computer and its long-term functionality was continuously monitored. This is referred to as the “control stencil-reworked Laptop” in Table 2 that shows the appraisal of the stencil-reworked process within an 8 months period. The total number of stencil-reworked Laptops and PCs was 188, 22 of which malfunctioned and were discarded. The total number of stencil-reworked Laptops and PCs that were delivered to customers was 166. The total number of stencil-reworked Laptops and PCs that were returned from the customers was 25, most of which with faulty cooling systems that most probably led to the failure of the stencil-reworked BGAs. The total number of stencil-reworked Laptops and PCs that were returned to the customers after further rework was 19, i.e. 6 stencil-reworked Laptops and PCs were discarded. Hence, the total number of stencil-reworked Laptops and PCs that were returned to the customers was 160 out of the initially delivered 166 which is a good rate. The control stencil-reworked Laptop showed no change.

ACKNOWLEDGEMENTS

The authors would like to thank Mr Chris Kilford (Augesco International Ltd) for kindly supplying the crumb rubber, and G. Filtsos and K. Papavramidis (Technicians, Computer Systems) for their valuable assistance.

REFERENCES

[1] P. Frantzis, P. Karydopoulos, and S. Villiotis, “Development of crumb rubber reinforced elastomeric/semi-elastomeric thermally conductive composite materials to be used as permanent ball grid array stencils in printed circuit board rework,” *MSAIJ*, vol. 10, no. 1, pp. 20-29, October 2013.

[2] P. Karydopoulos, P. Frantzis, and S. Villiotis, “Permanent elastomeric/semi-elastomeric ball grid array (BGA) stencils,” Greek Patent No GR 1008100, May 2014.

[3] P. Frantzis, P. Karydopoulos, and N. Karagiannis, “Development of semi-elastomeric thermally conductive crumb rubber reinforced cementitious composites to be used as permanent ball grid array stencils in printed circuit board rework,”*MSAIJ*, vol. 11, no. 3, pp. 97-104, March 2014.

[4] P. Frantzis, P. Karydopoulos, and N. Karagiannis, “Structure of ball grid array/permanent semi-elastomeric thermally conductive crumb rubber reinforced stencil/printed circuit board interconnects,” MSAIJ, vol. 10, no. 10, pp. 431-437, March 2014.

[5] P. Frantzis, “Environmental attack on adhesive joints. Part III: Mechanisms of failure,” *JSME Int.J., Ser. A*, vol. 41, no. 3, pp. 405-415, July 1998.

[6] P. Frantzis, “Crumb rubber-bitumen interactions: Diffusion of bitumen into rubber,” *J.Mater.Civ.Eng.*, vol. 16, no. 4, pp. 387-390, July/August 2004.

[7] J. E. Galloway and B. M. Miles, “Moisture absorption and desorption predictions for plastic ball grid array packages,” *IEEE Trans. Comp., Pack. Manufact. Technol., Part A*, vol. 20, no. 3, pp. 274-279, September 1997.

[8] P. Frantzis, “Environmental attack on adhesive joints. Part II: Locus of failure,” *JSME Int.J., Ser. A*, vol. 41, no. 3, pp 395-404, July 1998.

[9] P. Frantzis, “Durability of adhesive joints made underwater,” *J.Mater.Civ.Eng.*, vol. 25, no. 10, pp. 635-639, October 2008.

[10] M. Gedeon. (July 2011). “Coating electrical contacts.” *Brush Performance Alloys*. No. 31. (Available: http://materion.com/~/media/Files/PDFs/Alloy/Newsletters/Technical%20Tidbits/Issue%20No%2031%20-%20Coating%20Electrical%20Contacts).