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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

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ABSTRACT

This work relates to the development of a new family of cementitious composites to be used as the material of permanent stencils for the rework (removal, repair, and replacement) of BGA (Ball Grid Array) components that can be found on a PCB (Printed Circuit Board). The rework involves the use of stencils to solder an array of new micro-balls arranged in a grid manner below the BGA. A stencil is a membrane that consists of arrays of perforations arranged in a grid manner. The membrane is produced from a composite that is made by mixing synthetic rubber latex, cement, and crumb rubber. The thermal conductivity of the composite was measured by a method also developed in this work. The new family of stencils transfers knowledge from the field of composites to the field of PCB rework and may uniquely provide the subsequent development of a new, easier, repeatable, predictable, low cost, rework method. Other benefits include increase in thermal conductivity, reinforcement with crumb rubber, inhibition of whisker formation/growth, no cleaning is necessary, and no need to use adhesives.

KEYWORDS

BGA stencil;
Rework;
Semi-elastomeric;
Crumb rubber;
Cement;
Thermal conductivity.

INTRODUCTION

The BGA 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, 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 BGA component that is found to be faulty is removed from the PCB, cleared of the balls, cleaned, and reballed, i.e. soldering a new set of matching balls onto the pads of the BGA. Reballing involves the use of BGA stencils to aid with the soldering process. A BGA stencil is a perforated membrane (of thickness between 0.2-0.9 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. Finally, the BGA is transferred to the rework area to resolder the new set of balls of the BGA onto the PCB lands. BGA metal stencils are made from stainless steel and are removed after use. Flexible stencils are also used that are made from a polymer film and are removed after reballing. Another type of stencil is made from a polyimide film and this is a permanent stencil[1].

The constant evolution of new tools, materials, and methods for rework could make the process more reliable and repeatable. One should stay abreast of new developments by constantly seeking for innovative ways to improve rework methods. Therefore, this work is concerned with the development of CEMENSTENCIL, a family of new BGA stencils that are made from a semi-elastomeric composite material that in turn is made by mixing synthetic rubber latex used in the construction industry, cement powder, and water treated crumb rubber powder. The new stencil is permanently fixed between the soldered balls, the BGA, and the PCB. Similar methods currently in use employ stencils that are made from polyimide materials that are permanently fixed between the soldered balls, the BGA, and the PCB. The new BGA stencils are cut from thin sheets of the composite and drilled to form the stencils and do not require any cleaning processes. CEMENSTENCIL may uniquely provide the development of a new, easier, repeatable, predictable, rework method, and the possibility of eliminating the application of the resoldering process of the new set of solder balls and thus at least one fewer thermal cycle for the BGA component[1,2]. The stencil could be made to reduce the temperature of the BGA by transferring heat from the soldered joints to the heat-sink system of the application by monitoring the thermal conductivity of the material of the stencil. The composite could therefore include up to 67% by weight of the neat latex material of commercially available ordinary cement powder that can act as a thermally conductive filler to enhance the thermal conductivity of the stencil. The composite could also include up to 43% by weight of the neat latex material of commercially available crumb rubber powder reinforcement produced from discarded car/truck tyres to increase the toughness of the stencil[1]. A method for measuring the thermal conductivity of the composite in air at room temperature was also developed. The new stencils have 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. The new semi-elastomeric stencils, in addition, have the potential to inhibit whiskers formation and growth in the solder joints by surrounding and continuously compressing the joints. No such work has been reported in the literature before.

EXPERIMENTAL

Materials

All basic materials used were commercially available. The semi-elastomeric materials were made from a 1-component cold-setting liquid synthetic rubber latex, the type of latex used in construction, namely Planicrete. The cement powder that was used to increase the thermal conductivity of the latex material was a general purpose ordinary cement. 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 latex/rubber/cement bond[1]. All mixing was carried out in plastic beakers by hand. The latex material was mixed with various amounts of cement powder and water treated crumb rubber powder without the addition of water. This type of latex is used in construction by mixing it with cement powder and water. The mixture was laid up on a flat surface. The flat surface was first cleaned and then coated with a thin layer of release agent. It was found that a sheet of the composite material of thickness 0.3-0.4 mm was easily produced. To measure the thermal conductivity of the sheets, a method suitable for use in electronics laboratories was developed. Finally, in rework trial tests, a BGA component was reballed using a CEMENSTENCIL. The reworked BGA was then transferred to a rework station, i.e. specifically built machines[1], and soldered to a PCB. The reworked PCB was next fitted into a laptop computer that was then switched on and its short-term functionality was assessed.

RESULTS AND DISCUSSION

Semi-elastomeric stencils

Figure 1 is a photograph of typical semi-elastomeric stencils produced by mixing the latex binder with 50% (by weight of the neat binder) cement powder, (a), and the same binder with 42% cement powder and reinforced with 8% (by weight of the neat binder) of water treated crumb rubber powder, (b).

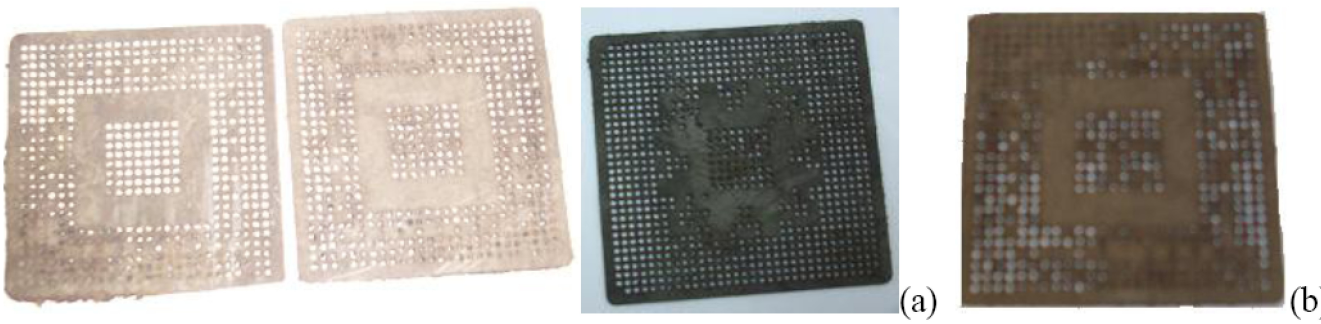

Figure 1 : Typical CEMENSTENCILS (0.4 mm thickness and cross-sectional area 23x23 mm^2) made with latex 50% cement powder, (a), and latex 42% cement powder 8% water treated crumb rubber powder, (b).

It is claimed that the stencils produced here were made from a semi-elastomeric composite in the sense that the sheet of the material is able to bend by a considerable amount without cracking. In fact, the sheets were found to be so flexible that they were able to fold over their side without any visual cracking, Figure 2, thus showing a considerable improvement in toughness. This property is more than sufficient for use as new permanent BGA stencils. However, the material appears to be able to accommodate minimal tensile elongation, as assessed by visual examination. The function of the new stencil is to aid to the reballing process by holding the micro-balls firmly within its apertures. The stencils are not subject to any mechanical stress during reworking other than the possible small amount of bending due to operator's error. The thermal conductivity of the composites produced was measured using a method developed here, as described below.

Method of measurement of the thermal conductivity of thin solid samples

Figure 3 shows a schematic representation of the concept of measuring the thermal conductivity of a solid sample of a material. Q is the quantity of heat flowing through the sample's cross-sectional area A and over a length ΔL across which a thermal gradient exists, $\Delta T/\Delta L$. T_1 and T_2 are the temperatures measured over the length ΔL and $\Delta T = T_1 - T_2$[3].

Then, the thermal conductivity, K, is given by the ratio of the heat flux, Q/A, to the thermal gradient, $\Delta T/\Delta L$, i.e.

$$K = (Q/A)/(\Delta T/\Delta L) \quad (1)$$

The heat produced from a heater could be calculated by measuring directly the electrical power supplied to the heater[3]. Figure 4 shows the electric heater used in this work that is connected to a heating gun that gives out a constant jet/flow of hot air, Q. The value of Q was taken to be 600 W, the maximum electrical power consumption supplied by the manufacturer. It was not possible to know the relation of the temperature of the hot air coming out from the gun to the electrical power consumption of the heater, and the maximum value of 600 W was therefore used in the calculations. When the thermal conductivity of a solid sample is high, the amount of heat flowing through it is high and the heat lost from the sample's lateral surface is small. A high temperature gradient is established in this case and it is possible to measure it accurately. When the thermal conductivity of a solid sample is low, the corresponding heat flowing through it is low and the heat lost from the sample's lateral surface, Q', is high. The heat flux was assumed to be uniaxial. Therefore, the solid samples produced here for the purpose of measuring the thermal conductivity of the composite were thin enough to reduce lateral heat losses, in the range 0.4-1.45 mm. That was sufficient to generate a measurable thermal

(a)

(b)

Figure 2 : Typical sheet (0.4 mm thickness) of a composite latex 42% cement powder 8% water treated crumb rubber powder, (a), and the same sheet folded over its side, (b).

gradient. Usually, the sample is packed inside insulation to minimize heat losses. Without installation of insulation, the heat losses are difficult to control. Commercially available apparatus using plastic/composite samples with thicknesses in the range 3-5 mm provide good insulation, but come at a relatively high cost. In this work, the measurements of the thermal conductivity of the composites were carried out in air at room temperature. Therefore, a graphical technique was used to account for the cumulative heat losses (lateral and/or

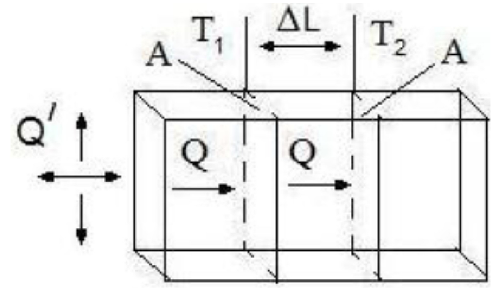

Figure 3 : Schematic representation of K concept

other possible heat losses) during the experimental procedure.

Detailed description of experimental procedure

Figure 4 shows the AOYUE Soldering Station Heating Gun (dimensions of gun mouth 12x12 mm^2) set to give out a jet/flow of hot air at 90°C. The station is part of standard equipment in electronics laboratories.

Figure 5 shows the experimental set-up. This Figure shows how a typical semi-elastomeric thin squared solid sample (dimensions 35x35 mm^2 and 0.4-1.45 mm thickness) is placed at a distance of 10 mm from the mouth of the gun. Next, the heater is turned on and measurements of the temperatures at the centre of the area A, T_1 (inner surface, i.e. the face of the sample next to the mouth) and T_2 (outer surface) are taken after 5 minutes (to allow a steady-state of Q to be reached) and at a 1 minute intervals, using an IR Thermometer (Figure 4). To establish the new method of calculating K in air, to include an account for the heat losses, various samples of known K values were used. These samples were in the form of thin squared plates (dimensions 25x25 mm^2) from copper (K = 400 W/m C and thickness ΔL = 0.14 mm), aluminium (K = 250 W/m C, ΔL = 0.53 mm), steel (K = 16 W/m C, ΔL = 0.45 mm), thermally conductive pad used in electronics laboratories (K = 1.7 W/m C, ΔL = 0.3 mm), and glass (K = 1.05 W/m C, ΔL = 0.58 mm). A sample was also cut out from the side of a food can with thickness ΔL = 0.25 mm. The samples were placed in front of the gun mouth and measurements were taken and recorded. Next, a graphical technique to account for the total heat losses was used that was a plot of the experimentally obtained K values, using Equation (1), against the actual K values, as shown in Figure 6.

Note that the area A in Equation (1) was taken to

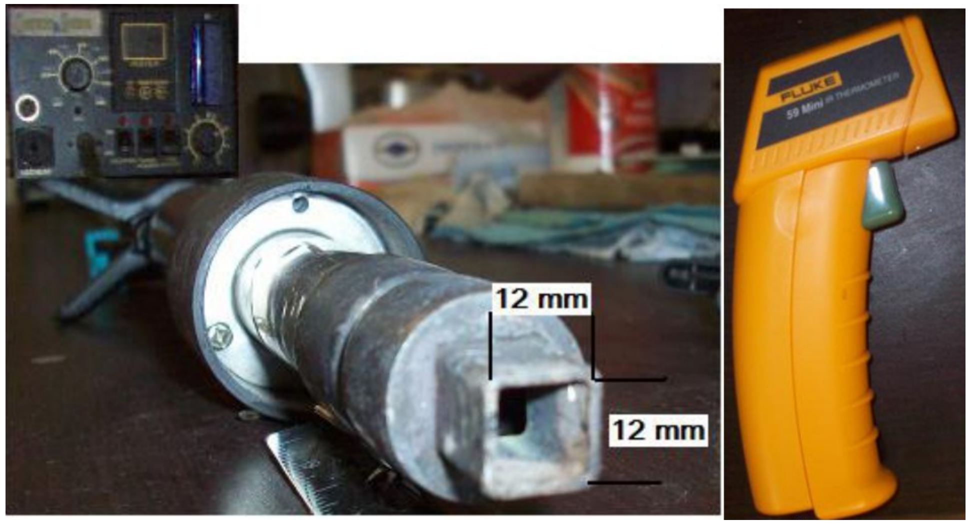

Figure 4 : Electric heater and gun (dimensions of mouth 12x12 mm^2), and IR Thermometer.

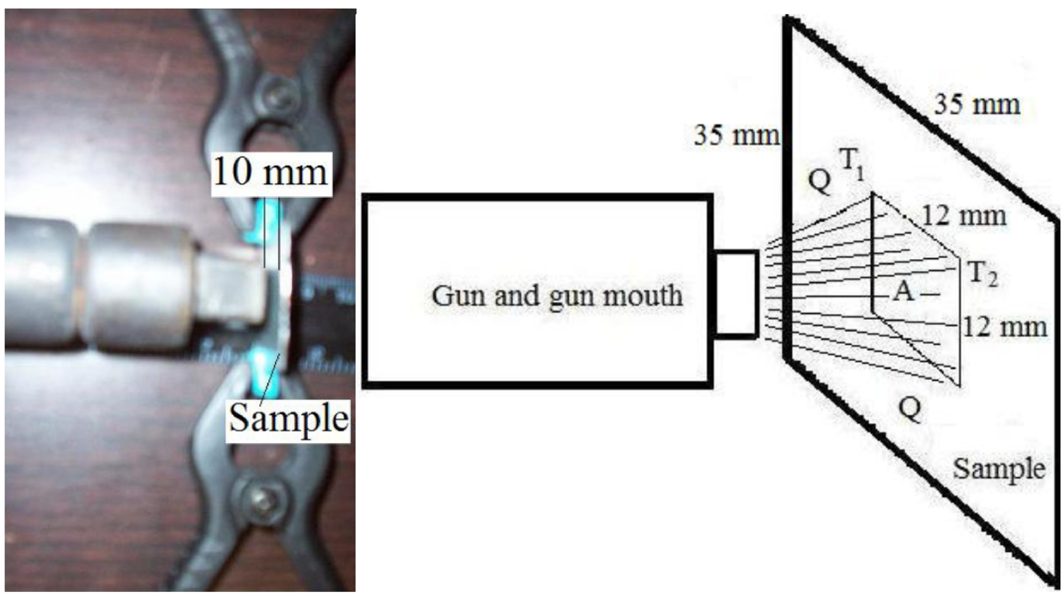

Figure 5 : Method and experimental arrangement showing a thin solid sample in front of the gun mouth and at a distance of 10 mm.

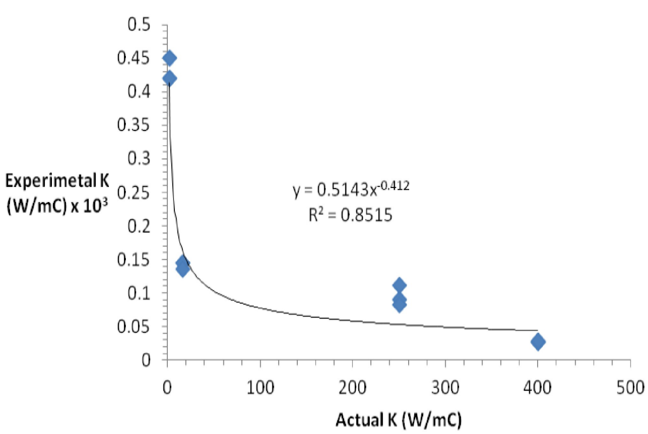

Figure 6 : Plot of experimentally obtained K values against actual K values.

be 12x12 mm^2, i.e. the dimensions of the mouth of the gun, Figure 5. Hence, an account for the heat losses was made by the use of Figure 7 that is derived from Figure 6 and can be used for the determination of low K values.

From the plot in Figure 7 an empirical relationship is derived as follows:

K experimental = 0.5574 (K actual)$^{-0.494}$ and therefore

$$K = 0.311\ (1/K\ \text{experimental})^2 \quad (2)$$

Equation (2) was used to calculate the K values of the composites produced here. In order to examine whether the method developed gives reliable and reproducible data, the sample cut from the side of the

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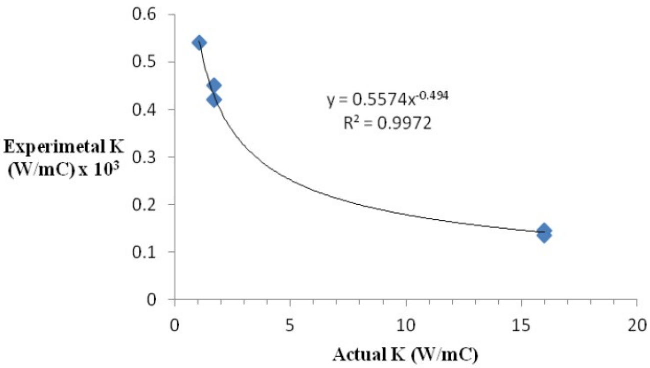

Figure 7 : Experimental K against actual K for low K values.

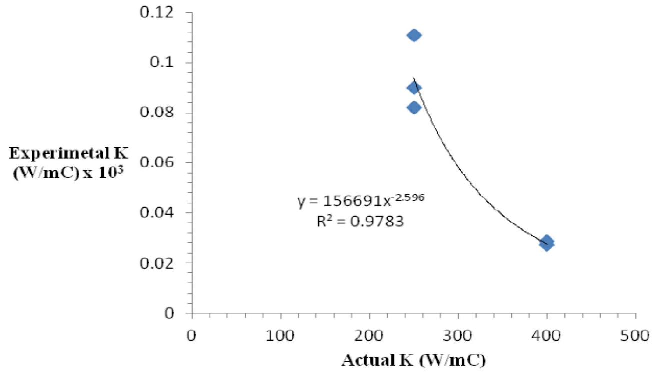

Figure 8 : Experimental K against actual K for large K values

food can was used. Next, the test procedure just described was applied and typical data obtained is shown in TABLE 1.

TABLE 1 : Typical data obtained using the food can sample.

T_1	T_2	ΔT
53.6	43.8	9.8
53.8	43.2	10.6
56.6	42.6	14.0
57.0	44.0	13.0
58.2	45.2	13.0
58.6	43.8	14.8
58.4	45.6	12.8
58.6	45.4	13.0
59.0	45.2	13.8
		Average ΔT = 13

The sample of thickness ΔL = 0.25 mm and average ΔT = 13, i.e. the food can sample, has been found here to have an experimentally obtained value of K in the order of 0.081x10^3 W/m C, using Equation (1).

This together with the data in Figure 8, that is derived from Figure 6 and shows a plot of experimentally obtained K values against actual K values for large K, yields a value of K between 250-260 W/m C, indicating that the material of the side of the food can is most probably made from aluminium. The literature reveals that the use of aluminium in food cans began in 1957. Aluminium is less costly than tin-plated steel but offers the same resistance to corrosion in addition to greater malleability, resulting in ease of manufacture. This gave rise to the two-piece can, where all but the top of the can is stamped out of a single piece of aluminium. Hence, the top is tin-plated steel and the side of the can is aluminium. However, the basic material used for most food cans in the UK is steel[4].

Hence, the range of K values obtained in this work, using Equation (2), is given in TABLE 2.

TABLE 2 : K values obtained in this work

K (W/m C)	Composite
0.362	Latex 29% Cement
1.697	Latex 41% Cement
4.024	Latex 50% Cement
4.053	Latex 60% Cement
5.016	Latex 67% Cement

The amount of cement in the composites in TABLE 2 varied between 29-67% (by weight of the neat latex binder) and shows a material with considerable increase in K suitable for use in electronic applications. It has been reported that the addition of 30% Boron Nitride filler to a resin results to a material having a typical thermal conductivity in the order of 1.5 W/m C[5]. The thermal conductivity of ordinary cement powder is 0.29 W/m C[6]. The thermal conductivity of ordinary cement mortar has been reported to be 0.739 W/m C[7]. The conventional lightweight concrete has been found to have a K value in the range 0.303-0.476 W/m C[8]. The thermal conductivity of cement pastes has been reported to lie in the range 0.52-0.719 W/m C[9]. A cementitious grout that also contained latex has been reported to have a thermal conductivity in the range 1.5-2.423 W/m C[10]. The thermal conductivity of conductive epoxy based adhesives used in the electronics industry has been reported to be in the range 0.7-3.5 W/m C[11]. The thermal conductivity of heat transfer compounds also used in the electronics industry is reported to lie between 0.9-3.0 W/m C[12]. Hence, the range of the values of the thermal conductivity reported here for the various composites is comparable to those reported in the literature.

Rework trials

Figure 9 shows a reworked PCB in which a BGA was removed and then replaced using a CEMENSTENCIL.

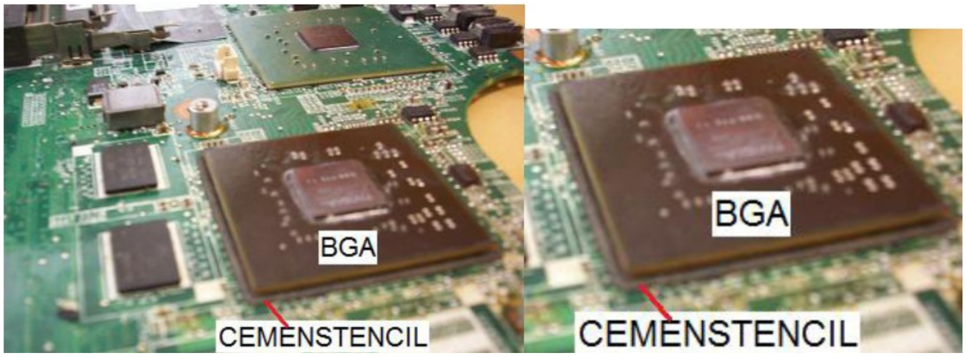

Figure 9 : Typical reworked PCB showing a BGA on top of the CEMENSTENCIL.

The CEMENSTENCIL can be seen underneath the BGA. In Figure 9, the stencil was purposely cut to a larger size to allow easy viewing to the reader. The reworked PCB was then placed in a laptop and standard tests were carried out in the specialized electronics rework laboratory. It was found that the function of the reworked PCB was normal. Further tests are envisaged to assess the long-term behaviour of the reworked PCB.

Whisker growth and corner/edge bonding

Tin (Sn) whiskers result in failure risks due to solder balls bridging caused by fixed and broken-free whiskers. Whiskers are electrically conductive single crystal structures of Sn and have been found to develop from the surface of pure Sn and Sn alloy coatings or high Sn alloy finished surfaces. They can cause two major reliability problems, mechanical and electrical. Experimental results and observations appear to support the hypothesis that the driving force for whisker formation is compressive stress and that imposed tensile stress seems to slow down the built-up process of compressive stress[1]. The use of the new permanent CEMENSTENCIL may give rise to this intentionally induced tensile stress by applying a continuous compressive stress via the stencil to the solder joints. Further work is envisaged.

Adhesives for bonding of BGA packages to PCBs are being used to prevent cracking of the solder joints due to thermal or mechanical flexing of the PCB. Corner bonding is one way of under-filling that is also thought to provide a mechanical shock absorbing system in case the device is subjected to impact stress like dropping. Another approach, namely edge bonding, is under-filling the whole of the BGA area by injecting an adhesive under the device after it is soldered to the PCB. The edge bonding process is thought to have the additional advantage of inhibiting whiskers formation/growth by surrounding the solder joints[1]. Another benefit of using the new permanent CEMENSTENCIL could come from 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. Further work is envisaged.

CONCLUSIONS

The work reported here relates to the development of CEMENSTENCIL, a new family of cementitious composites to be used as the material of permanent stencils during the rework (removal, repair, and replacement) of BGA (Ball Grid Array) components that can be found on a PCB (Printed Circuit Board). The new stencils could be made from a semi-elastomeric sheet of a composite material that in turn could be made from synthetic rubber latex used in the construction industry, cement powder, and crumb rubber powder. The term semi-elastomeric is used here in the sense that the sheets of the material are so flexible that they are able to fold over their side without any visual cracking, thus showing a considerable improvement in toughness. The development of CEMENSTENCIL transfers knowledge from the field of composite materials to the field of PCB rework. This may uniquely provide the subsequent development of a new, easier, reliable, repeatable, predictable, and with low cost rework method. Other benefits include the elimination of the stencil cleaning process, ability to increase the thermal conductivity, reinforcement with crumb rubber, ability to inhibit whisker formation/growth, and rendering the use of adhesives unnecessary. In addition, a method for measuring the thermal conductivity of thin solid materials in air has been developed. The method could be particularly suited for use by research electronics laboratories. It is envisaged that millions-upon-millions of discarded laptops could be back from the brink of being hauled to a dump and reused bringing extra benefits to owners. PCBs used in high-risk applications (aviation, shipping, and military applications) could be reworked using low cost CEMENSTENCIL to extend the service life and offer a more reliable operation.

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