ISSN : 0974 - 7486 Volume 10 Issue 1

Materials Science

An Indian Journal

Full Paper

MSAIJ, 10(1), 2013 [20-29]

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

Panagiotis Frantzis*, Panagiotis Karydopoulos, Sotiris Villiotis
Computer Systems, Didimotixou 29, Neapolis, 56727 Thessaloniki, (GREECE)
E-mail: frantzis@computer-systems.gr

ABSTRACT

This work relates to the development of a new family of materials to be used 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 micro-balls arranged in a grid manner below the BGA. A stencil is a membrane consisting of arrays of perforations (micro-holes or apertures) arranged in a grid manner. The new stencils, with the balls fitted into the apertures, are initially attached below the BGA, and finally are fixed between the soldered balls, the BGA, and the PCB. Similar methods employ polymer stencils that are initially fixed between the soldered balls and the PCB, and finally are fixed between the resoldered balls, the BGA, and the PCB. The development of the new stencils may uniquely provide a new, easier, repeatable, predictable, low cost, rework method eliminating resoldering of the balls that also gives the benefit of one fewer thermal cycle for the BGA component. Other benefits include reinforcement with crumb rubber, increase in thermal conductivity, inhibition of whisker formation/growth, no need to use adhesives, and recycling of discarded stencils.

KEYWORDS

BGA stencil;
Rework;
Elastomeric;
Semi-Elastomeric;
Crumb rubber;
Recycling.

INTRODUCTION

The BGA is a very different electronic device compared to those using pins[1-3]. The pins of the BGA package are copper (with a Ni/Au surface finish) 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 to provide the required connectivity. The BGA packages offer many advantages over other packages and as a result they are increasingly used for the manufacture of electronic circuits. In a typical family of BGAs, the solder balls may be of diameters ranging between 0.4 to 1.0 mm and the total number of balls could vary from 30 up to 700. BGAs are currently used extensively in mobile phones, computers, modems, handheld devices, office environment equipment, and in aviation, shipping, and military applications.

A BGA component that is found to be faulty is removed from the PCB by simultaneously heating the BGA and the PCB to melt down the solder balls between them[1-3]. The BGA is then removed, 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 of the new set of balls onto the BGA. A BGA stencil is a perforated membrane (of thickness between 0.2 to 0.9 mm) which consists of arrays of perforations (micro-holes or apertures) that are 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 and a heat reflow profile is applied, with a peak temperature set at 220°C giving a local maximum temperature of 250°C, to resolder (reflow) the new set of balls of the BGA onto the PCB lands[4-6].

Rework of BGAs often combines three methods of transferring heat energy into the device, i.e. convection, conduction, and radiation. Successful rework requires special tools, knowledge, and experience. During reballing and reworking, stresses are induced into the BGA through multiple thermal cycles that could damage the component.

Metal stencils for reballing have been in use for decades and are typically made from stainless steel[7]. After use, the metal stencil is carefully removed. A relatively new method is the use of flexible stencils[7]. These stencils are cut and drilled from a polymer film and are initially attached to the PCB. The stencil is then carefully removed. An alternative method is to use a stencil that remains in place on the PCB[7,8]. The stencil material is a polyimide film. After the solder balls are flowed onto the lands of the PCB, the stencil is not removed from the PCB. Solder ball preforms are also used[4,5]. The preform is an array of solder balls suspended in a removable backing material. After the solder balls are flowed onto the BGA component or onto the lands of the PCB, the backing material is removed. Preforms require the use of very specialized tools. Another method is laser soldering that eliminates two thermal cycles and enhances BGA component reliability[9].

The constant evolution of new tools, materials, and methods for rework could make the process more reliable and repeatable. These improvements vary from being relatively simple using polymer stencils to more complicated using preforms and laser technology. 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 a family of new non-metallic stencils that are made from elastomeric/semi-elastomeric materials in which, after the balls are fitted into the apertures of the stencil, the stencil/balls system is initially attached to the lower part (bottom side that contains the pads) of the BGA, and finally is permanently fixed between the soldered balls, the BGA, and the PCB. Similar methods currently in use employ non-metallic stencils that are made from polyimide materials that are initially fixed between the soldered balls and the PCB, and finally are permanently fixed between the resoldered balls, the BGA, and the PCB. The new BGA stencils are cut from thin sheets of the matrix composite materials and drilled to form the stencils. The new stencils may uniquely provide the development of a new, easier, repeatable, rework method, and the elimination of the reflow (resoldering) process of the solder balls and thus at least one fewer thermal cycle for the BGA component. The stencil material could include up to 43% by weight of the neat material of commercially available crumb rubber powder reinforcement produced from discarded car/truck tyres. The stencil material could also include up to 30% by weight of the neat material of commercially available thermally conductive filler that could be mixed with the materials to enhance the thermal conductivity of the composite. A heat transfer compound could also be mixed with the binders in cases where mixing with the filler is not possible. Thermally conductive paints could also be used in cases where mixing with the filler and the compound is not possible. The paint could be applied over both sides of the sheets. Discarded semi-elastomeric stencils could be grinded to flakes and recycled in cement, should the need to replace the BGA arise again. The new stencils also 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. The new stencils, in addition, have the potential to inhibit whiskers formation and growth in the solder joints by surrounding and compressing the joints. No such work has been reported in the literature before.

EXPERIMENTAL

Materials

All basic materials used were commercially available. The elastomeric materials were made from a 2-component cold-setting liquid silicone rubber and a 1-componenet cold-setting liquid latex emulsion based on natural rubber concentrate that was pre-vulcanized and ready for use. The semi-elastomeric material was formed by using a 2-component cold-setting crystal polyester resin. The crumb rubber powder (produced by an ambient grinding process) was from car tyres (synthetic rubber) of 0 to 0.2 mm (200 μm maximum, 60 mesh) particle size. Ready-made (i.e., commercially available) sheets (of thicknesses 0.25 to 0.45 mm) of latex were also used for comparisons. The thermally conductive filler was Boron Nitride powder with mean particle size 0.5 μm. The heat transfer compound was based on silicone. The thermally conducted paint was based on an epoxy adhesive. The cement powder used for the recycling trials was a general purpose quick setting cement with water/cement = 0.6.

Methods

The crumb rubber was treated using the water activated method[10,11] prior to mixing with the matrix materials. It has been reported that the rheological properties of bitumen are improved with the addition of water treated crumb rubber[10], and that the addition of 10% (by weight of the neat binder) of water treated crumb rubber to bitumen results to a binder with (fatigue) strength suitable for use as an all-weather wearing course in flexible roads whilst at the same time recycling a considerable amount of waste rubber[11]. A quantity of deionized water was added to the particles to form a slurry. The rubber/water ratio was 1:2. The slurry was heated to 90°C and heating continued for a further 20 minutes at this temperature. The addition of water and the elevated temperatures caused the particles to expand which enabled excess oils, chemicals, and some residual metals in the particles to be released. This was observed by the change in the colour of the water. The slurry was next dried in an oven and the particles were ready for mixing with the binders. All mixing with the matrix materials was carried out in plastic beakers by hand to include mixing at various crumb rubber concentrations up to 43% by weight of the neat material of the matrix. Perspex moulds with spacers to the required thickness of 0.3 – 0.4 mm were used to form sheets of the matrix materials. For rubber concentrations greater than 17% the sheets could be produced by cutting away layers from bulk form of the matrix materials using a *guillotine*. The sheets included up to 30% by weight of the matrix material of the thermally conductive Boron Nitride filler to increase the thermal conductivity of the composite in an effort to reduce the temperature of the BGA by transferring heat away from the solder balls via the stencils to the main heat-sink system of the application. The silicone compound was mixed with the materials at a concentration of up to 30% by weight of the matrix material when mixing with Boron Nitride was found to be not possible. The ready-made latex sheets had the potential to be coated over both sides using the thermally conductive adhesive. All sheets were cut to size and drilled to form the stencils. The apertures of sample stencils were next manually fitted with micro-balls and the stencils were placed on top of the lower side of a BGA (which was held bottom side up) that contains the pads. The BGA was next placed into a heater/cooler and heated from room temperature to 250°C (i.e. the heat reflow profile maximum temperature) followed by cooling. In rework trial tests, flux (to minimize the risk of oxidation which is standard practice in electronics manufacturing industry and in rework laboratories) was applied over the lower side (that contains the pads) of a BGA component (which was held bottom side up) and the stencil/balls system was attached by gluing it to the flux and making sure that each ball sited exactly on the designated pad of the BGA. The reworked BGA was then transferred to a rework station, i.e. specifically built machines[13-15], 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. Finally, in recycling trial tests, semi-elastomeric stencils, containing crumb rubber particles or Boron Nitride, were grinded by hand using a mortar and piston and mixed with cement. The water/cement ratio was 0.83 and the mixtures included 17% of treated crumb rubber particles and 17% of flakes (i.e. a mix of resin/Boron Nitride and resin/treated crumb rubber). The setting time of the mixtures produced was less than 10 minutes. The surfaces to be examined were produced by fracturing samples of the composite material using a hammer. The samples were then examined under an optical microscope, Moritex MS-400 at magnifications x20 and x50, which was connected to a monitor. Images of the microstructures were viewed through the monitor and photographs were taken.

RESULTS AND DISCUSSION

Elastomeric stencils (silicon rubber/latex)

Figure 1 is a photograph of a typical latex stencil of 0.4 mm thickness.

Figure 2 is a photograph of a typical latex stencil

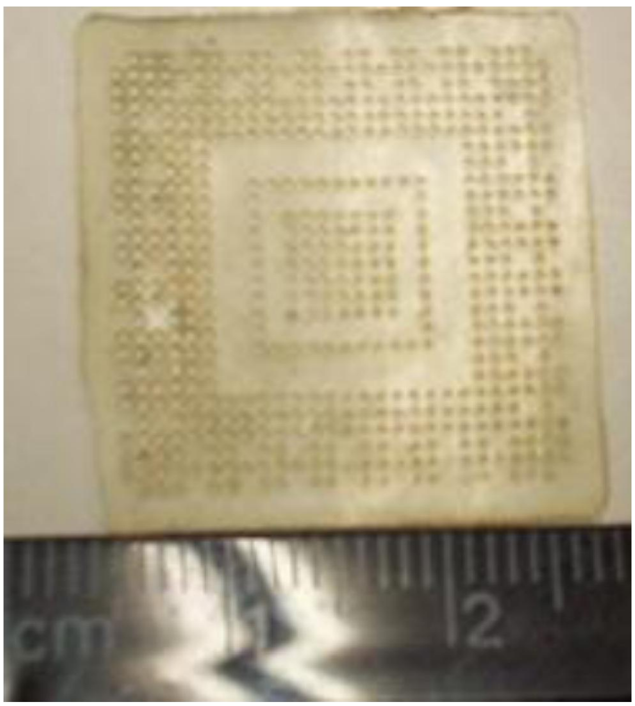


Figure 1 : Typical latex stencil.

(0.4 mm thickness) reinforced with 17% by weight of the neat binder of treated crumb rubber powder (left) and a typical latex stencil (0.4 mm thickness) reinforced with 12% by weight of the neat binder of treated crumb rubber powder and including 30% by weight of the neat binder of silicon compound (right). Note that the latex material could not be mixed with Boron Nitride.

The latex stencil without any reinforcement was

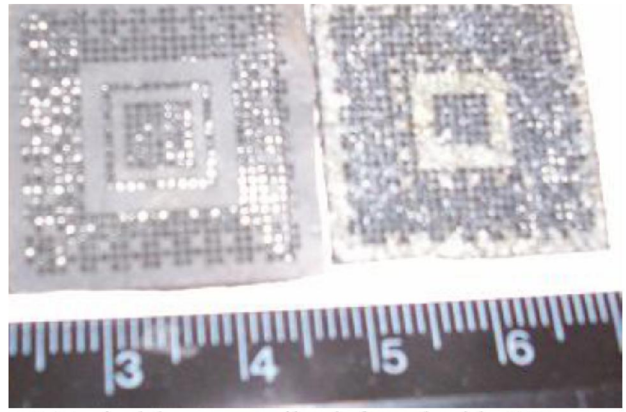


Figure 2 : Typical latex stencil reinforced with 17% water treated crumb rubber powder (left) and typical latex stencil reinforced with 12% of water treated crumb rubber powder and including 30% silicon compound (right).

placed on top of the lower side of a BGA and then placed in an oven and subjected to thermal cycling/cooling from room temperature to 250°C. Figure 3 shows that the solid latex stencil was transformed into a gelatinous latex stencil but remained firmly in place on top of the lower part of the BGA with the balls in position. The blue stencil was made from a ready-made sheet and is included here for comparison.

The objective of work reported in the literature[16,17]

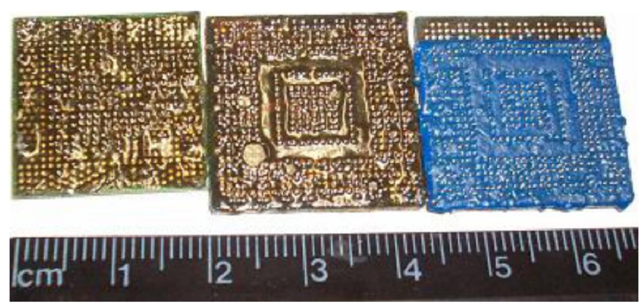


Figure 3 : Typical gelatinous latex stencils on top of the lower side of BGAs at room temperature and showing balls in position.

was to investigate the influence of temperature dependent flow properties (thermal flow) of (paper) latex (binders) on calender (a machine that smoothes or glazes/glosses over paper or cloth by pressing it between plates or passing it through rollers) runnability (the tendency to deposit formation on the calender surface that was a measure of flow). A number of types of latexes with different temperature dependent flow properties were investigated. The experiments were performed on coated liquid packaging board using an extended soft nip pilot calender with surface temperatures up to 250°C. It was found that some types of latexes had high flow ability at elevated temperatures and others had much lower ability. A type of a latex investigated showed comparatively high ability to flow in the 20°C to 50°C range and rather low ability to flow over 80°C. The results suggested that sticking due to excessive adhesion to calender surface was the dominant mechanism[16,17]. Returning to the work carried out here, it is possible that the latexes used fall within the types of latexes that have low ability to flow at all temperatures. Indeed, the gelatinous latex stencils were found to be very sticky and stiff at room temperature after exposure of the solid latex stencils to a heating/cooling cycle up to 250°C and therefore this may explain the results. Hence, the latexes could be used as the gelatinous materials of permanent BGA stencils. It was found that the latex material could not be mixed with Boron Nitride but only with the silicon compound. The use of the Boron Nitride, the silicone compound, and the thermally conductive paint, is subject to further research and will not be discussed here. Reinforcing the latex material with 17% crumb rubber powder results to a solid material being formed at all temperatures. Attention was focused on to the latex material because the silicon rubber material always produced solid stencils at all temperatures and crumb rubber content. Another reason is the cost of the latex material that is much lower compared to the silicon rubber material. The use of the silicon rubber is subject to further research.

Semi-elastomeric stencils (Crystal polyester resin)

Figure 4 is a photograph of a typical crystal polyester resin stencil reinforced with 17% by weight of the neat resin of water treated crumb rubber powder.

It is claimed that the stencils produced here were made from a semi-elastomeric composite material in the sense that the sheet of the material produced is able to bend by a considerable amount before fracturing, whereas a sheet of the resin alone is very brittle and will fracture almost instantly. It has been reported that[18] the use of crumb rubber in resins to improve some properties is practically not feasible. The results suggested that[18] modification of resins with crumb rubber cannot achieve the desired toughness improvement. However, researchers still use crumb rubber in resins usually to target toughness improvement. It is well known that rubber particles when dispersed in micron-scale range may improve the fracture toughness and fracture energy of the corresponding resin matrix[19]. This holds also true for treated crumb rubber[19]. In this study, the sheets of the treated crumb rubber powder reinforced resin were found to have a semi-elastomeric behaviour due to their ability to flex considerably. In fact, the sheets were found to be able to fold over their side before fracture compared to sheets of the resin material alone thus showing a considerable improvement in toughness, in agreement with results reported elsewhere[19]. This property is more than sufficient here for use as new permanent BGA stencils. The function of a new stencil is to aid to the reballing process by making the placement of the balls into the apertures easier and by holding the balls firmly within the 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.

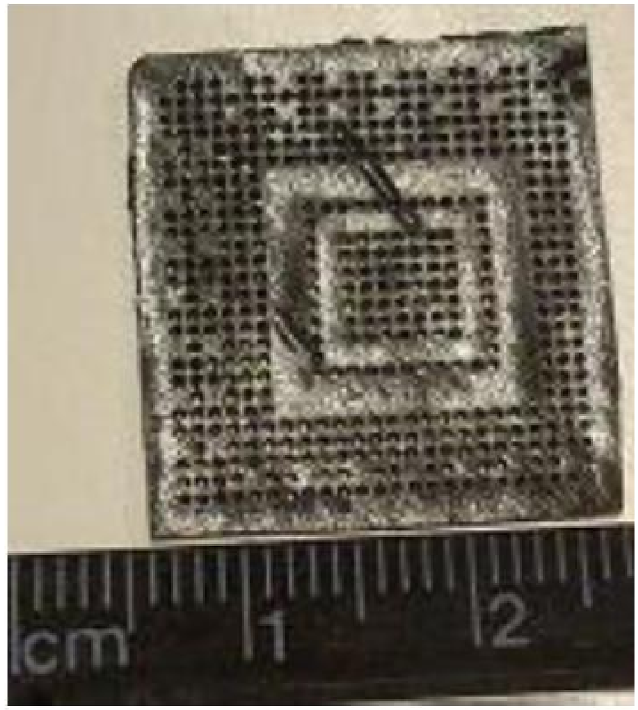


Figure 4 : Typical crystal polyester resin stencil reinforced with 17% water treated crumb rubber powder.

Resins on the other hand play an important role as binders for crumb rubber in construction and civil engineering applications. An industrially produced material reported in the literature is a composite of two-components, i.e. resin and crumb rubber, and it is used for filling expansion joints in bridge decks and other concrete structures[20]. It is claimed that the flexibility of the composite material can accommodate sufficient tensile elongation thereby facilitating safe joint movement caused by thermal cycles and traffic loading[20]. It is also claimed that the composite is completely impervious and prevents any ingress of moisture, chlorides, salts, and other corrosion inducing substances[20]. A somewhat similar composite material has been produced here under laboratory conditions that is subject to further research.

Figure 5 is a photograph of a typical (laser cut/drilled thus showing usual burns) crystal polyester resin stencil containing 30% by weight of the neat resin of Boron Nitride filler.

Mixing of the polyester resin with 30% by weight

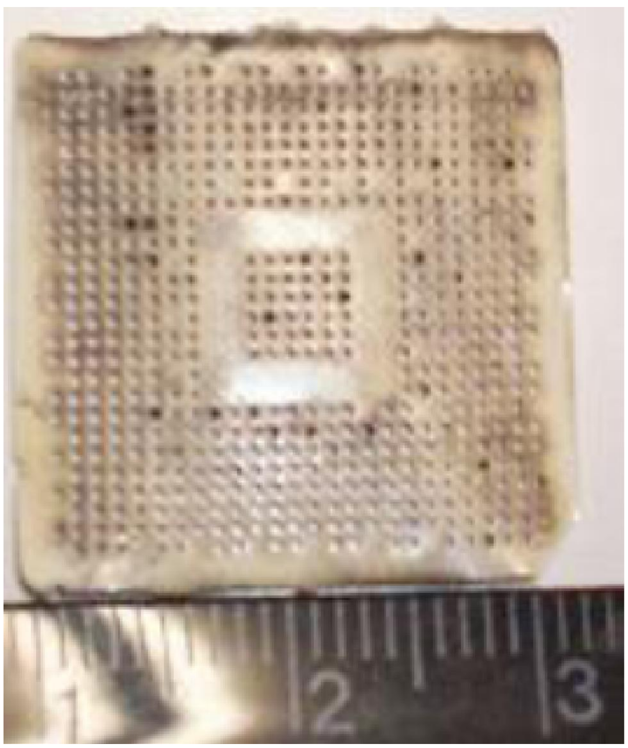


Figure 5 : Typical laser cut/drilled crystal polyester resin stencil containing 30% Boron Nitride.

of the neat resin of Boron Nitride filler was found to be possible. It has been reported that[21] the addition of 30% Boron Nitride to a resin results to a material having a typical thermal conductivity in the order of 1.5 W/mk which in the electronics industry translates into a material having a good thermal conductivity. It was not possible to measure the thermal conductivity of the composite material produced here, and therefore, it was assumed to having a thermal conductivity similar to the one reported in the literature[21].

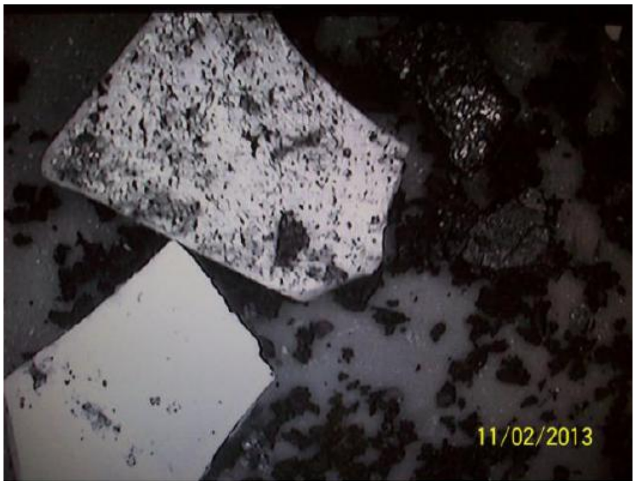
Recycling trials

Figure 6 is a typical image produced from optical microscopy that shows grinded semi-elastomeric flakes (black regions due to resin/crumb rubber particles and white regions due to resin/Boron Nitride particles) at magnifications (a) x50, (c) and (d) x20, and particles of water treated crumb rubber (black regions) at magnification (b) x50, prior to mixing with the cement matrix material.

Crumb rubber is also used in cementitious materials[22,23] and Figure 7 shows a typical image of microstructure of water treated crumb rubber particles (small black regions) and flakes (larger white regions) within the cement matrix (grey regions) at magnifications (a) x20 and (b) x50.

Note that sieve analysis or particle size distribution analysis of the flakes was not carried out here. These findings are analogous to work reported in the literature of homogeneous microstructures obtained using a metallographic microscope with reflecting objective (Olympus microscope) where crumb rubber particles appeared as black regions in the bituminous (grey regions) matrix[24], and work using scanning electron microscopy (SEM) that showed micrographs of homogeneous fibrous microstructures as black/dark regions (fibres) within the aluminium alloy (grey regions) matrix[25]. Figure 7 shows a homogeneous microstructure and therefore evidence of strength and hence recycling of the discarded stencils was assumed to be feasible. Note that strength development measurements were not carried out here since the purpose of this work was to assess whether recycling of discarded stencils is possible. Visual examination of the samples produced revealed that the samples appeared to be rock-solid, Figure 8. Further work is envisaged.

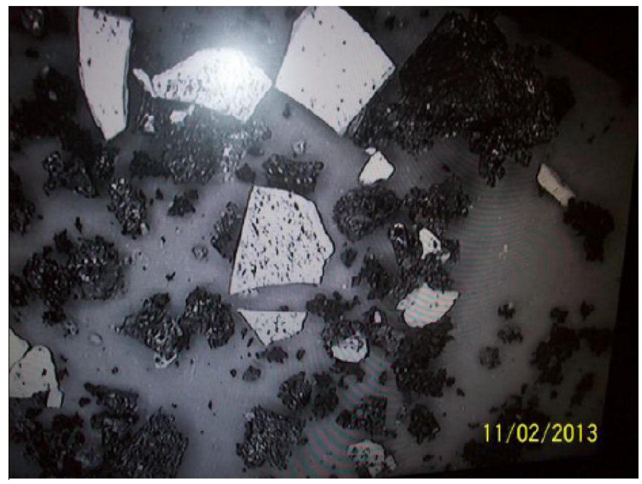
An article on the uses of recycled glass suggests that[26] crushed glass could be used as aggregate in construction, in accordance with EU legislation that increases the required amount of recyclable material to be taken out of the waste stream. Crashed glass could therefore be used to promote the development of industrial uses of recycled glass. Hence, flakes obtained from grinded BGA stencils could also be used to pro-



(a) Flakes x50

(b) Crumb rubber x50

(c) Flakes x20



(d) Flakes x20

Figure 6 : Typical images of flakes (a, c, d) and crumb rubber (b) particles prior to mixing.

a) Cement fractured surface x20

b) Cement fractured surface x50

Figure 7 : Typical images of flakes and crumb rubber particles within the cement matrix.

mote the development of industrial uses of discarded PCB parts.

Rework trials

Figure 9 shows a reworked PCB in which the BGA

Figure 8 : Typical cement sample reinforced with 34% recyclable materials (17% water treated crumb rubber and 17% flakes).

was removed and then replaced using a latex reballed stencil.

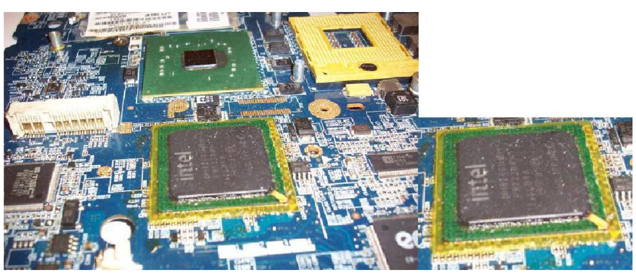


Figure 9 : Typical reworked PCB showing a BGA (black region surrounded by the green region) on top of the (yellow) latex gelatinous stencil.

The sticky and stiff gelatinous (yellow) stencil can be seen underneath the BGA. In Figure 9 the latex 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

It has been reported that tin (Sn) whiskers result in failure risks due to solder balls bridging caused by fixed and broken-free whiskers[27-29]. 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. They can grow without electrical field, in vacuum, and in atmosphere, with unknown growth rates, and it is believed that they may start to grow soon after soldering or lie dormant for years. It is also believed that 50°C is the optimum temperature for whiskers to grow and it has been reported that 25°C is more favourable. One concern with whiskers is the inability to inspect for whisker risk during manufacturing. Even though the issue of metal whiskers has been studied for over 60 years, currently there is no accepted model and no industry-wide accepted methodology to quantify whisker risk. Experimental results and observations appear to support the hypothesis that the driving force for whisker formation is compressive stress. The origination and magnitude of this compressive stress is still under extensive studies. It is reported that imposed tensile stress seems to slow down the built-up process of compressive stress. The use of the new permanent stencils may give rise to this intentionally induced tensile stress by applying a continuous compressive stress via the stencils to the solder joints. Further work is envisaged.

An epoxy or cement based adhesive for bonding of BGA packages to PCBs in order to prevent cracking of the solder joints due to thermal or mechanical flexing of the PCB has been reported[30]. The under-fill solution provides both creep mitigation and enhancement of thermo-mechanical fatigue reliability. Corner bonding is one way of under-filling. The main purpose of a corner bonding adhesive is to provide with a mechanical shock absorber, i.e. to promote additional adhesion to lessen stress induced to the solder joints in case the device is subjected to a mechanical 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 has the additional advantage of inhibiting whiskers formation/growth by surrounding and compressing the solder joints[27]. Another benefit of using the new elastomeric/semi-elastomeric stencils could come from their 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 development of a new family of BGA stencils transfers knowledge from the field of 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[31]. It is claimed that the corner/edge bonding process, where part or the whole of the area between the BGA and the PCB is filled using an adhesive that cures to form a solid body, has the advantage to act as a mechanical/thermal shock absorber. There is no reason to argue that the new family of permanent elastomeric/semi-elastomeric stencils to include the gelatinous stencils, where the area between the BGA and the PCB is filled by a non-solid shock-absorbing material, does not have the potential to act in a similar way. Another benefit of using the new permanent stencils, which surround the joints, may come from their additional advantage of inhibiting whiskers formation/growth by applying a continuous compressive stress to the solder joints. This compressive stress then may give rise to an induced tensile stress in the joint that resists whisker formation/growth. Hence, the new stencils may render the use of adhesives unnecessary. In addition, PCB waste may be reduced by recycling discarded parts bringing extra benefits to the industry and the environment, should one day most of the parts have the potential to be recyclable. It is envisaged that millions-upon-millions of discarded laptops could be back from the brink of being hauled to a dump while in the EU alone more than 10 million laptops could be reused bringing extra benefits to owners. PCBs used in high-risk applications (aviation, shipping, and military applications) could benefit from being reworked using the new stencils to extend the service life and offer a more reliable operation.

ACKNOWLEDGEMENTS

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).

The authors would like to thank Mr Chris Kilford, Augesco International Ltd, for kindly supplying the crumb rubber powder.

REFERENCES

[1] MicroStar BGA Packaging Reference Guide, Texas Instruments, Literature Number: SSYZ015B, Third Edition (21/Feb/2013·www.ti.com/lit/wp/ssyz015b/ssyz015b.pdf), **(2000)**.

[2] What is a BGA (21/Feb/2013·www.jlab.org/accel/eecad/pdf/044bgapackages.pdf), **(2013)**.

[3] A new stencil RuleBook (21/Feb/2013·www.smtnet.com/library/files/upload/A%20New%20Stencil%20Rulebook.pdf), **(2013)**.

[4] BGA Reballing Instructions, Emulation Technology Inc., USA (21/Feb/2013·www.emulation.com), **(2013)**.

[5] SIX SIGMA Inc, Milpitas, USA (21/Feb/2013·www.sixsigmaservices.com), **(2013)**.

[6] HEPCO Inc., Sunnyvale, USA (21/Feb/2013·www.hepcoblue.com), **(2013)**.

[7] R.Cirimele; BGA Rework: A Comparative Study of Selective Solder Paste Deposition for Area Array Packages, BEST Inc., ILLinois, USA (21/Feb/2013·www.smtnet.com/library/files/upload/SMT_PANPAC_Paper_Rev032704.pdf), **(2013)**.

[8] StencilQuik™ Patent Pending, BEST Inc. (21/Feb/2013·www.solder.net/products/stencilquik), **(2013)**.

[9] J.Muonio, R.Stadem; Solder ball attachment using laser soldering, Circuits Assembly, 2008 (21/Feb/2013·www.analogtech.com/Solder%20Ball%20Attachment%20Using%20Laser%20Soldering.pdf), **(2013)**.

[10] M.Mohammed; Activated Method for Treating Crumb Rubber Particles, Patent Number US 5927620, **(1999)**.

[11] P.Frantzis; J.Mater.Sci., **38**, 1397 **(2003)**.

[12] Application Note: RC BGA Rework Procedure, Number AN-RC1-RW-A, CTS Corporation.(21/Feb/2013·www.ctscorp.com/components/Datasheets/RCBGAReworkProcedureA.pdf), **(2005)**.

[13] A Publication of the National Electronics Manufacturing Center of Excellence, ACI Technologies Inc (21/Feb/2013·www.empf.org/empfasis/june04/bga.htm), **(2004)**.

[14] Survey of Rework Methods/Equipment and Contract Manufacturers for Various Packaging Technologies, Nasa, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA (21/Feb/2013·www.Nasa Survey of Rework Methods/Equipmentand), **(2005)**.

[15] BGA Rework, Advanced Techniques Inc., Warminster, USA (21/Feb/2013·http://atco-us.com/data/applications/4301919874a1c3d6d90468.pdf), 18974 **(2009)**.

[16] R.Carlsson, P.Salminen, M.Wikström; Influence of Latex Binder Viscoplastic Properties on High Temperature Calendering Runnability, Paper presented at the TAPPI Coating Conference, TAPPI Press, Atlanta, USA. (21/Feb/2013·http://www.tappi.org/Downloads/unsorted/UNTITLED—ctg02457pdf.aspx), **(2002)**.

[17] R.W.Eklund, L.D.Erickson, H.G.LeBlanc; The Response of Single and Multi-Component Carboxylated Styrene-Butadiene Latex Coatings to Soft Calendaring, Paper presented at the TAPPI Coating Conference, TAPPI Press, Atlanta, USA. (21/Feb/2013·http://www.tappi.org/Downloads/unsorted/UNTITLED—90may153pdf.aspx), **(1990)**.

[18] J.Karger-Kocsis, L.Mészáros, T.Bárány; J.Mater.Sci., **48**, 1 **(2013)**.

[19] J.Karger-Kocsis; In J.Karger-Kocsis, S.Fakirov, (Eds); Nano- and micro-mechanics of polymer blends and composites, Hanser, Munich, 425 **(2009)**.

[20] Castec Inc, Rubbercrete (T-22) Rubber/Epoxy Joint Material Technical Data Sheet (21/Feb/2013·http://www.transpo.com/pdfs/Rubbercrete_spec.pdf) **(2013)**.

[21] M.J.Hodgin, R.H.Estes; Advanced Boron Nitride Epoxy Formulations Excel in Thermal Management Applications, Paper presented at the NEPCON WEST Conference, Anaheim, CA, 23 – 25 Feb, (21/Feb/2013·https://www.epotek.com/SSCDocs/whitepapers/Tech%20Paper%2042.pdf), 359-366 **(1999)**.

[22] N.I.Fattuhi, L.A.Clark; Construction and Building Materials, **10(4)**, 229 **(1996)**.

[23] N.N.Eldin, A.B.Senouci; J.Mater.Civ.Eng., **5**, 478 **(1993)**.

[24] P.Frantzis; J.Mater.Civ.Eng., **20(10)**, 419 **(2003)**.

[25] P.Frantzis; ISRN Materials Science, ID 757218, **(2011)**.

[26] N.Wilks; Message in a Bottle, Professional Engineering Magazine, **13(4)**, 34 **(2000)**.

[27] R.D.Hilty; Tin Whiskers in Electronics Components, Tyco Electronics, Harrisburg, USA (21/Feb/2013·www.te.com/customersupport/productcompliance/pdf/tyco lf customer packet whiskers.pdf), **(2013)**.

[28] Q.Sun, G.Selvaduray; Understanding and Minimizing Tin Whiskers: A Review of the Literature, Chemical & Materials Engineering Department, San Jose State University, USA. (21/Feb/2013·www.sjsu.edu/faculty/selvaduray/page/recent/TinWhiskers.pdf), **(2003)**.

[29] T.Fang; Tin Whisker Risk Assessment Studies, Phd Dissertation, University of Maryland, USA. (21/Feb/2013·http://drum.lib.umd.edu/bitstream/1903/3079/1/umi-umd-2889.pdf), **(2005)**.

[30] Nordson Asymtek Corporation, West Carlsbad, USA (21/Feb/2013·www.circuitnet.com/experts/panel_426.shtml), **(2013)**.

[31] P.Karydopoulos, P.Frantzis, S.Villiotis; Permanent Elastomeric/Semi-Elastomeric Ball Grid Array (BGA) Stencils, Patent Pending Application No GR 20120100613 **(2012)**.