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Analysis of the quality of the welding process in the exchange of component of BGA technology

Análisis de la calidad del proceso de soldadura en el cambio de componente de tecnología BGA

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ABSTRACT: In recent years, many efforts have been expended by companies in the search for technological improvement of their products by adding features such as lightweight materials, reduced size and high levels of performance at the lowest cost, to meet a worldwide demand in this regard. This article aimed to conduct an analysis of the quality of the *Reflow* of soldering in exchange of component of BGA technology. The methods and techniques used were the qualitative-quantitative approach, conducted by the case study technique in the welding process of the BGA component by collecting (*cross section* and X-ray) and data analysis (alignment, cracks and voids) within the process. The achieved results showed that the Reflow welding process in the exchange of BGA component meets the criteria for acceptance of international standards IPC -A - 610E and IPC 7095B. This fact leads to the inference that the quality of the process in question may reflect in better conditions and cost competitiveness for the investigated organization.

RESUMEN: Actualmente muchos esfuerzos están siendo realizados por las empresas en busca del perfeccionamiento tecnológico de los productos, agregando aspectos tales como ligereza, reducción de las dimensiones y altos niveles de desempeño al menor costo posible para atender una demanda mundial en este sentido. El objetivo de este artículo fue realizar un análisis de la calidad del proceso *Reflow* de soldadura en el intercambio de componente de tecnología BGA. Los métodos y las técnicas utilizados tuvieron un enfoque cualitativo-cuantitativo, orientado mediante la técnica de estudio de caso en el proceso de la soldadura del componente BGA mediante la recopilación (*cross section* y rayos X) y el análisis de datos (alineación, grietas y vacíos) dentro del proceso. Los resultados alcanzados demostraron que el proceso de Reflow de la soldadura en el intercambio del componente BGA cumple los criterios de aceptación de las normas internacionales IPC – A-610E e IPC 7095B. Este hecho lleva a inferir que la calidad del proceso en cuestión puede influir en mejores condiciones de costo y de competitividad para la organización investigada.

1. Introduction

The periodic revolution in electronic devices in last years is motivated by the integration of intelligence in the functionalities of these devices. The evolution of the technology in electronic components of these products causes, by effect, a miniaturization of the components and an increase in operating performance, following the trend in electronic devices toward smaller and lighter devices with increased functionality [1]; however, the miniaturization turns the assembly and welding of these components more complex, demanding a control level of the process every time higher.

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The researched company presents, in its Productive process of Printed Circuit Mother Board (PCI MB) of Laptops, a stage in which a change of components of BGA technology carried out, due to some bad operation, and it can be said that it is very difficult to verify and to prevent the failures, because they are caused by several factors, such as thermal - mechanics and shock stresses [2]; however, the company ignores the quality level of the welding process accomplished in this change of BGA, and such knowledge is important because the more an organization invests in preventive tasks, the less failures will occur in the process

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and the manufacturing cost will drop or at least the costs will remain as predicted in the manufacturing planning. The consequence of the cost reduction and the quality improvement reflects directly on the profit, due to the fact that the company must keep the same product prices [3].

Therefore, the objective of this article was to develop a research to diagnose the quality of the welding process of a component of BGA technology, after the change of this component in PCI's MB of Laptop in a company of the Industrial Pole of Manaus (PIM). During 2013, the company in study went through a migration from Tin-Lead Welding Technology to Lead-Free Welding, assisting an international demand; however, this transition worsens the process problems because the lead-free welding is usually harder and more brittle than conventional lead and tin welds [4]. One of the unintentional consequences of this migration is that the industry had to request new methods for the welding of components in the boards; this comes in one moment in which the industry of semiconductors is developing components continually smaller and accommodating higher functionalities [5]. The research is justified based on the need of a diagnosis of the welding process in the implantation phase, because the use of materials and processes exempt of lead, also conduces to new concerns with the quality [6], becoming this type of research indispensable for any organization that tries to offer to their customers a quality product, avoiding thus that the company assumes reliability risks of their products when offer them in the market. This research could become a reference for future works inside of the organization.

2. Bibliographical Revision

2.1. Ball Grid Array (BGA)

The Components of the type Ball Grid Array (BGA) are commonly used in microelectronic industry that works with high-density pins (terminal), good heat transfer and low cost [7]. The BGA Technology is one of the most attractive and thoroughly used encapsulation option because of many benefits, as the reduction of coplanarity problems, reduction of the size, better electric and thermal performances etc. [8].

BGA is used in several types of components, among them, chipsets and memory chips. It is a component type where the contact terminals are spheres. Figure 1 shows a BGA component and its balls.

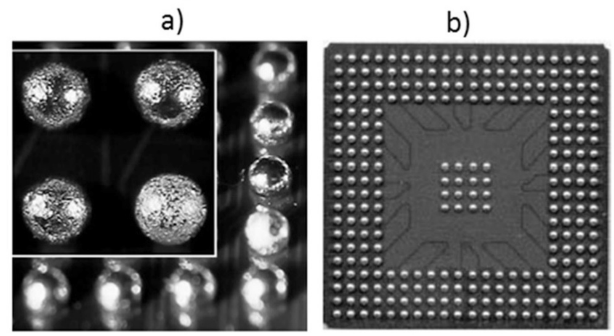

Figure 1 View of the BGA Component: a) Zoom of the Spheres of the component; b) BGA Component [9]

The Mother Board that receives this component passes by the SMT typical process: Printing of Welding Paste, procedure of welding paste application, assembly of the component (Place Component) and welding in a re-fusion furnace. After welding of the BGA on the PCI, the spheres (Balls) are not visible. Figure 2 illustrates the flow of the SMT process for the BGA component [9], in this process (1) it shows the PCB, (2) the printing of the welding paste on the PCB, (3) the assembly of the BGA component and (4) the welding of the component.

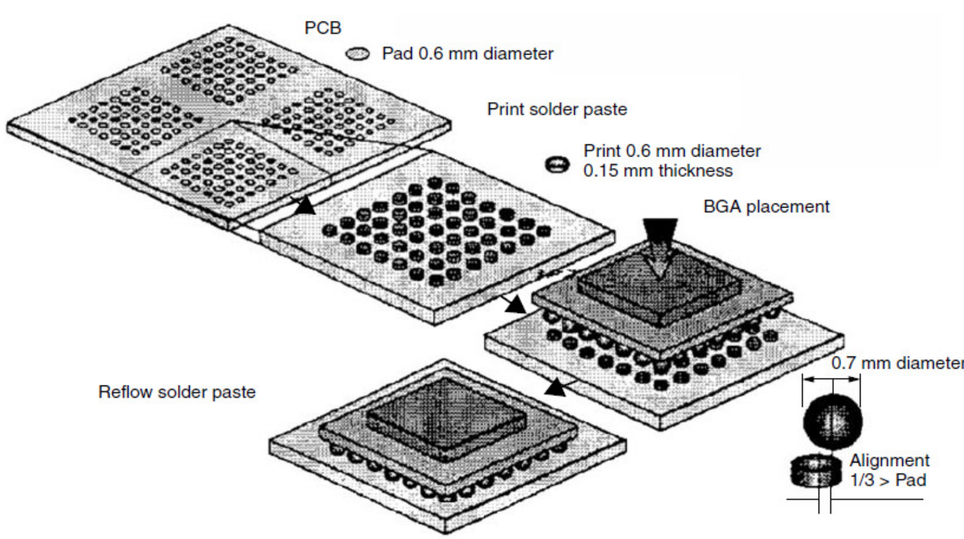

Figure 2 Flow of the process of assembly of a BGA [9]

2.2. Description of the welding process of the BGA Component

The Reflow Process is a part of the process of Surface Mount Technology (SMT), technology where the components are mounted directly on the surface of the printed circuit board [10]. Processes of SMT assembly lines usually involve welding paste, placement of components and the operations of Reflow Welding [11]. The Reflow welding process consists of heating up the whole mounted board to liquefy the solder paste to form welding unions between SMDs and PCB without altering the original characteristics of the electric components. It is used a reflow furnace to heat up the mounted boards to an appropriate temperature in a specified period of time to a tax of appropriate heating [12]. A characteristic model of recommended profile is described in the Figure 3 [12]:

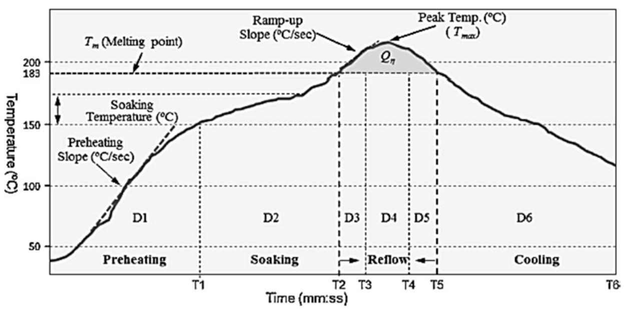

Figure 3 a) Temperature distribution during the welding process. The shadow zone corresponds with the liquid state of the soldering [12]

In the cases in that the BGA component presents a defect, for the accomplishment of the change of the component, it is used a specific Station of Change of BGA, so that the placement of the component is more accurate. This process should also be carried through a controlled temperature profile to avoid defects in the welding of Balls. In general, the heating profile for removing the component is the same as for the assembly of the component [9]. When a BGA component change is going to be carried out, it is recognized that a process control is essential for obtaining an appropriate result. As previously affirmed, the normal process to accomplish the reworking is to try to emulate the Reflow profile production for the individual component to be substituted [13].

2.3. IPC Standard

The IPC - *Association Connecting Electronics Industries* is a global commercial association devoted to the competitive excellence of their filial companies around the world. IPC serves to the industry of electronic, specifically to the manufacturers related with the process of Printed Boards with acceptability patterns internationally accepted [14].

The IPC Standards and Publications are projected to serve to the public interest through the elimination of misunderstandings between manufacturers and buyers, facilitating the interchangeability and improvement of products, and aiding the buyers in selecting and obtaining the appropriate product with minimum delay for their particular need [15].

Among the existent Certifications in IPC, this article used the IPC-7095B, which focuses on the information in critical inspection, repair and problems of quality associated to BGAs [15].

2.4. Implementation of Lead-free Welding

The European Union approved a legislation named RoHS (Restriction of Hazardous Substances) Policy that prohibits the lead (Pb) use and several other substances in electronic products with beginning on July 2006 [16]. Starting from this year, the usage of one of the components more used in welding, lead, would not be more used in electronic welding due to this legislation. Among alternatives without lead, the lead-free welding (SnAgCu) is a substitute thoroughly accepted, due to its best fluency, its fatigues resistance and its microstructural stability [17].

One of the main differences between SnPb and SnAgCu welds without lead is that SnAgCu weld demands higher Reflow temperature than SnPb welds, the fusion point is 217 °C - 219 °C, superior to the SnPb weld temperature, that has a fusion point of 183 °C [18]. It is also necessary to verify the adaptation of the assembly components. Measures should be taken to protect the components against potential damage provoked by higher Reflow temperatures. The quality of unions and welding materials, and its adaptation for a certain application should be verified [19].

The BGA component is an example thoroughly used in printed circuit boards by a process of reflow welding, which is one of the critical items in Surface Mount Technology. Welding joins breakage is one of the main failure manners due to an inadequate lead-free reflow welding process [20]. Nowadays, Brazilian companies that export for the European Union countries have adopted RoHS and participated in programs of national auction, migrating for a welding technology without lead.

3. Materials and Methods

The following paragraphs describe the main methodological aspects employed in the preparation of this case study, where the main focus of the diagnostic study was the quality of the welding process performed in the exchange of components of BGA technology.

3.1. Nature of the Research

This work can be classified as a descriptive research that uses the technique of the case study as collection and analysis of data tool, with an approach so much qualitative as quantitative; the method of the case study allows the researchers to keep the holistic and significant characteristics of the events of the real life [21].

3.2. Definition of Research Opportunity

The use of components of BGA technology needs that companies carry out a complete monitoring of the process to assure the welding quality. The organization in study makes the change of this component type frequently, without a diagnosis of the quality level of the welding developed in this process.

This research was developed according to the process of change of components of BGA technology, and it had as objective to develop a study to diagnose the quality of the welding in this process. The study of this process of BGA welding was carried out because this phase is characterized as a very complex stage of the process due to the miniaturization of the components. The BGAs are developed as a viable solution for the demand of the industry and with this component type, the quality of the welded join became one of the more critical factors of the process [22].

3.3. About the Stages

For the case study, a literature review on the fundamental concepts related to the topic was used, searching recent papers on similar applications and International Technical Standards IPC-TO-610E and IPC-7095B, to diagnose the acceptance of the welding of the component type studied.

Initially, it was analyzed a theoretical framework through scientific papers where it was identified that the *cross section* and X-Ray tests are broadly used for this study type.

The *cross section* test was carried out in a certified laboratory of national recognition and the data of the tests were tabulated as well as the photographic images of the component obtained through electronic microscopy. The X-ray images were executed in the studied company. There were considered data of involved costs regarding two sceneries: 1 - To discard a PCI MB whose component BGA needed to be changed, because the company did not accomplish the change of BGA for the quality lack in the welding process; 2 - The company accomplished the change of the component BGA of the PCI MB.

3.4. Delimitation of the research

The studies of welding quality have wide application in several components in the electronic area and two types of tests are more commonly used for evaluating the welding: The Cross-section and the Dye & Pry.

This article is delimited to the study of a component of BGA technology of mechanical position U22 in the PCI MB of a Notebook and the type of mechanical test that was carried out is the *Cross-section* test that will show characteristics of the BGA's located in the right corner, in the left corner and in the center of the component. The voids of the welded balls after the component exchange were verified using the X-ray. As temporary delimitation, the PCI MB'S samples were collected between April and May of 2013, in such a way that made possible an attendance of the development of the process in sequential periods.

4. Results and discussions

This research was developed according to the study of the process of welding in the change of components of BGA technology, evaluating the quality of the welding. This activity is inserted in the process of production of Notebooks. The assembly and welding of the component in the process of change of BGA were accomplished by a Station of Change of BGA operated by technicians of repairing area of the company. The Figure 4 shows the component BGA and the Station of Change of BGA.

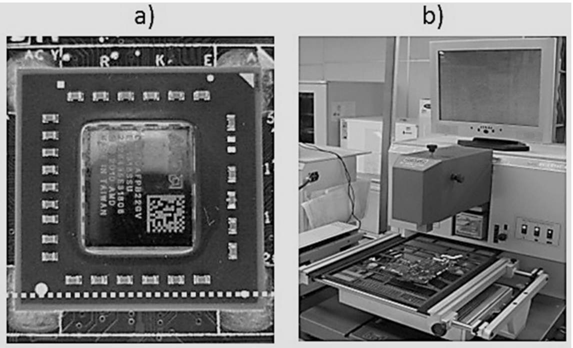

Figure 4 View of the BGA component and the device used for assembling and welding it. a) BGA Component; b) Station of assembling and welding the BGA Component. (Data organized by the author (2014))

In the period from April 01 to May 31, 2013, the acquisition of data verified that the amount of this model of produced Notebooks reached the total of 16,458 PCI MB and 177 BGAs were changed, corresponding to an index of 1.075%. After that, the costs of scrapping the PCI MB which presented welding quality problems in the BGA component were accounted as follows: The cost of a PCI MB is of $64.19, the total of PCI MB to be rejected would be of 177 units, doing a total cost of $11,361.63. Taking into account the amount of this model produced in 2013 (131,199 PCI MB), the projected

Table 1 Defect Index and Cost with discard of PCI MB

Component	% Defect	Cost with discard in the studied period	Cost with discard in annual period
BGA	1.075%	$11,361.63	$90,568.79

cost would be $90,568.79. The index of Defect and the Cost considering PCI MB'S discard is presented in Table 1.

From the identification of the BGA component for the analysis, a study to evaluate the welding of the component was carried out. As described in the methodology, the *Cross-section* and the X-Ray of the BGA were used as evaluation methods. The *Cross-section* test was carried out in an external certified laboratory of analysis, the data obtained for the BGA component from this test are presented in Figure 5.

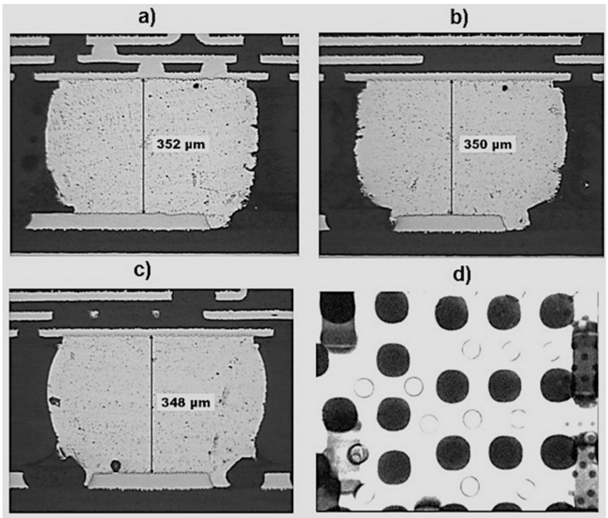

Figure 5 Zoom of the Cross Section and X-Ray of the BGA Component a) Sphere of the left corner b) Sphere of the right corner and c) Center Sphere d) Partial area of all the spheres. (Data organized by the author (2014))

Figure 5 shows the obtained images with a zoom 100X by means of an optical microscope of the cut of the BGA Ball of the left corner (a), right corner (b), Center Ball (c) and of the X-Ray carried out for identifying Voids (d).

4.1. Results Analysis

Analyzing the results of Figure 5 according to the requirements of the IPC A-610E and IPC-7095B it is possible to evidence that:

i) The alignment of the component is considered acceptable

The positioning of the BGA *solder ball* is centered and does not show any displacement of the Ball for the land centers [14] Figure 6a shows an image of the alignment of the Ball according to IPC A-610E.

ii) There were not found cracks in the Balls

Figure 6 shows the crack of one ball specified by the IPC A-610E, a crack of a ball and a ball without crack according to the IPC-7095B.

iii) There were not found voids in the Balls

The IPC-7095B [15] offers information about voids in BGA, including its sources, impact, detection and elimination, establishing a limit of up to 25% of the area of the *Ball*. Voids of great areas can produce reliability problems, because a reduced transversal section of the weld area has minor heat transfer, less mechanical load capacity, and less capacity of electrical current transport [23]. Figure 6 shows criterions for Voids according to IPC-7095.

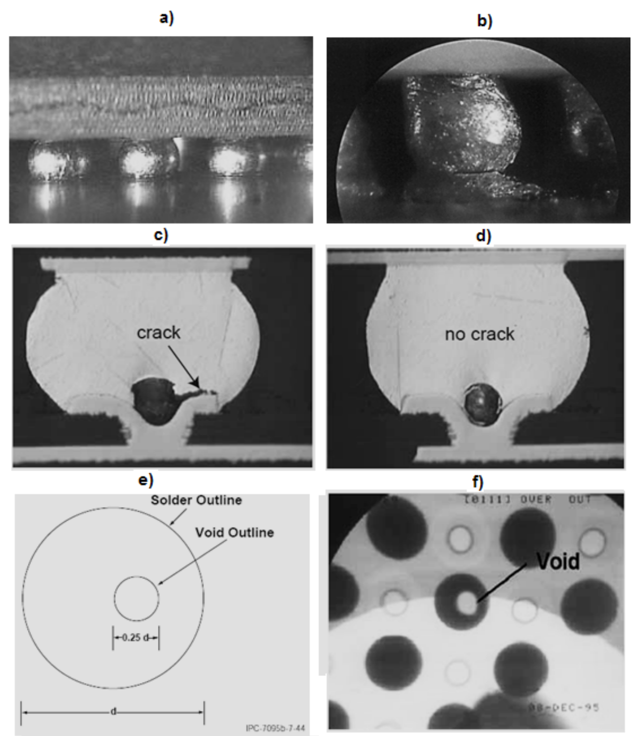

Figure 6 Images from the IPC standard for the criteria of acceptability: a) Alignment; b) Crack IPC A-610E; c) Crack IPC-7095B; d) No Cracks IPC-7095B; e) Acceptability of Void and f) Example of Void

Taking into account the data (i-iii) verified in the *cross-section* analysis of the BGA component according to the criteria of acceptability presented in Figure 6, it is possible to affirm that the weld join analyzed was found in compliance with the Standards IPC-A-610 and IPC-7095B, therefore, it can be said that the process of welding in the BGA exchange fulfills the international concepts of quality. The costs involved for the company in the case of exchange of BGA components are referring to the manpower (including the orders) and replacement of the component. The cost with manpower in the studied period was of $3,260.73, considering the annual production, the value would be of approximately $26,085.88. The cost with replacement of the component was of $1,371.18 ($7.75/component). In the studied period and considering the annual production, the value would be $10,925.98. These costs considering the exchange of the component are presented in Table 2:

Table 2 Index of Defect and cost with discard of PCI MB

% Defect	Cost with/ change in the studied period	Cost with/ change in annual period	Reduction % Cost in the studied period	Reduction % Cost Annual Period
1.075%	$4,631.92	$37,011.86	59.23%	59.13%

Observing Table 2, it can be appreciated a reduction of cost for the company in an average of 59% with this process of exchange of BGA when compared with the situation of discard of the PCI. All costs are expressed in USD dollars.

5. Conclusions

On the basis of the analysis of the results presented in Figure 5, it is possible to affirm that the company could perform the exchange process of a BGA component, inserted in the process of manufacture of notebooks, without risk in the final quality of the product, because the study of *cross-section* carried out in the BGA demonstrated that the executed process of welding attend the criteria of acceptability of International Standards IPC-A-610E and IPC-7095B, therefore, it can be concluded that there is quality in the welding process of the exchange of the component of BGA technology.

The values of cost offered in Table 2, referring to the process of exchange of the component, evidence that the accomplishment of this activity also reduces the cost that the company would have in case that the company had to discard the PCI MB, due to the lack of quality in the welding process. It is observed a reduction of 59% of the costs approximately.

Knowing the quality of its processes is essential, so that the company can work to get lesser costs and better conditions of competitiveness, then, this article could demonstrate the importance of the quality in the welding processes of BGA exchange becoming reference for future works inside the studied organization and for other companies which use BGA components in their manufacturing processes.

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