Design for Plastic Ball Grid Array Solder Joint Reliability

*S.-W. R. Lee, J. H. Lau**

The Authors

S.-W. R. Lee, *Department of Mechanical Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong*

J. H. Lau*, **Express Packaging Systems, Inc., Palo Alto, California, USA*

Abstract

Computational stress analysis was performed in this study to investigate the solder joint reliability of plastic ball grid array (PBGA) packages with various configurations. The packages under investigation were 27 mm body-size, 1.27 mm ball-pitch, perimeter PBGAs with and without thermal balls at the centre. The diagonal cross-section of the PBGA-printed circuit board (PCB) assembly was modelled by plane-strain elements. The model was subjected to a uniform thermal loading and the solder joints were stressed due to the mismatch of coefficient of thermal expansion (CTE). A total number of 24 cases, involving different solder ball populations, chip sizes, and substrate thicknesses, were studied. The accumulated effective plastic strain was evaluated as an index for the reliability of solder joints. The results of this study revealed the effects of the aforementioned parameters on the solder joint reliability of perimeter PBGA assemblies. The findings are very useful for the design of plastic ball grid array packages.

Keywords: Plastic Ball Grid Array, Reliability, Solder Joint.

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INTRODUCTION

In the past decade, the number of transistors and interconnections in microelectronic modules has increased substantially due to the advancement of semiconductor and packaging technology and the demands for higher and higher performance. The current trend in the electronics industry shows that, for modules with more than 208 pin counts, the area array packages will dominate.[1] There are many forms of area array packages for various applications. In particular, due to the cost-effectiveness and the ease of implementation, the plastic ball grid array (PBGA) package has become increasingly popular in the electronics industry. It is expected that the PBGA package will overwhelm the market for electronic modules with pin counts from large than 208 to 420 in the coming decade.[2]

One of the major advantages of PBGA packages is the compatibility with surface mount technology (SMT). For surface mounted modules, the solder joint is not only the passage of electrical signal, power and ground, but also the mechanical support to hold the module in position on the printed circuit board (PCB). It is well known that most solder materials are susceptible to low-cycle fatigue.[3] Since the dimensions of solder joints are relatively small and the electronic modules will experience thermal cycles during service, the reliability of solder joints for surface-mount components (SMC) is a main concern for the electronics manufacturing industry. It was identified that the stress and strain in solder joints are mainly induced by the mismatch of coefficient of thermal expansion (CTE) between SMC and PCB.[4] The induced stress and strain depend on material properties as well as package geometry.[5] Unlike other conventional SMCs with long leads such as quad flat packages (QFPs), the solder joint stand-off of PBGAs is rather short, especially due to the collapse of eutectic solder balls during reflow process. Since the shorter stand-off height results in less compliance for the relative deformation between SMC and PCB, the solder joint reliability is a critical issue for PBGA assembly.

In the literature, a few studies have been performed to investigate the solder joint reliability of plastic ball grid array packages with certain specific configurations.56 In the present study, a series of finite element analyses was conducted to simulate PBGA-PCB assemblies with various solder ball populations, chip sizes, and substrate thicknesses. The packages under investigation were 27mm body-size, 1.27mm ball- pitch, perimeter PBGAs with and without thermal balls at the centre. The diagonal cross-section of the specimen was modelled by plane-strain elements and subjected to a uniform thermal loading. In total, 24 cases were studied. The accumulated effective plastic strain was evaluated as an index for the reliability of solder joints. The results of this study revealed the effects of the aforementioned parameters on the solder joint reliability of perimeter PBGA assemblies.

FINITE ELEMENT MODEL

In this paper, a number of perimeter PBGA packages were studied. The package size and the die thickness were 27mm and 0.381 mm (15 mils), respectively, for all cases. The substrate was made of BT and was assembled to an FR-4 PCB by 63Sn/37Pb eutectic solder. The solder ball pitch was 1.27mm (50 mils). The material properties of all aforementioned package constituents are given in Table 1.6 There were three design parameters considered in the present study. These are solder ball population, chip size, and substrate thickness. In total, 24 cases were investigated. The configurations of various cases are presented in Table 2 and Figure 1. Since the thermal-loading response is most critical in the largest planar dimension, the diagonal cross-section was considered in the modelling. A schematic diagram for the layout of the PBGA-PCB assembly is shown in Figure 2.

A commercial finite element code, ANSYS, was employed in this study for stress analysis. The diagonal cross-section of the PBGA assembly was modelled by 8-node quadrilateral plane strain elements. Due to symmetry, only a half of the cross-section was simulated. All materials were assumed to be linear-elastic except that the solder balls were elasto-plastic. A uniform temperature loading from 0°C to 85°C was applied to the whole assembly. Within the scope of the present study, all material properties were assumed to be temperature independent.

RESULTS AND COMPARISON

The objective of the present study is to investigate the effect of certain design parameters on the PBGA solder joint reliability. The accumulated effective plastic strain in solder balls under uniform thermal loading was evaluated as an index for the solder joint reliability (Figure 3). The numerical results for all cases are presented in Figure 4Figure 5Figure 6Figure 7.

Figure 4 shows the profile of the maximum accumulated effective plastic strain in each solder ball for a.4-row perimeter PBGA without thermal balls. The total population of solder joints is 256 balls. Six cases were investigated for various chip sizes and substrate thicknesses. The concave shape of all curves reveals that there is a change of mechanism for building stresses in solder joints. It is observed that the innermost solder joint is strongly influenced by the chip size while the outer two solder joints are insensitive to the chip size for all cases. This phenomenon is attributed to the rather large CTE mismatch between the silicon die, BT substrate, solder ball and PCB, and the deflection of the whole assembly. For thinner BT substrate (0.27 mm), the maximum plastic strain always appears in the innermost solder balls. However, when the thickness of BT substrate is increased (0.54 mm), the plastic strain in the outermost solder joint becomes larger except for very big chip size (10 mm). It is interesting to note that a thicker BT substrate can considerably suppress the effect of CTE mismatch for the innermost solder joint, but, on the contrary, may result in more plastic strain in the outermost solder ball. This increase in plastic strain is due to larger global mismatch of thermal expansion from thicker BT substrate. Since the increased amount is relatively small, therefore, it is considered as having no effect on the solder joint reliability.

The numerical results for a 4-row perimeter PBGA with 16 thermal balls at the centre are presented in Figure 5. The total population of solder joints is 272 balls. It is seen that the trends for the four rows of perimeter balls are more or less the same as those observed in Figure 4. However, the plastic strain appears to be very high for the thermal balls. This indicates that the thermal balls will fail much earlier than the perimeter balls due to local thermal expansion mismatch and deflection of the whole assembly. Comparing the charts in (b) and (c), it is noted that the plastic strain in thermal balls can be substantially reduced by increasing the thickness of BT substrate (thus reducing the deflection of the whole assembly). Besides, it is observed that the chip size has reverse effects for thermal balls and perimeter balls, namely, for the former, the smaller the chip size, the higher the accumulated effective plastic strain. This is mainly due to the larger deflection of the whole assembly which has less flexural stiffness to resist bending. (Note that the Young's modulus of silicon die is five times higher than that of BT substrate.) For thicker BT substrate (Figure 5(c)), the effect of chip size on the plastic strain is minimal.

The major difference between the results shown in Figures 6/7 and Figures 4/5, respectively, is the magnitude of plastic strain in the innermost solder joints. Since this particular solder ball of a 5-row perimeter PBGA is closer to the silicon die than that of a 4-row one, it has a larger plastic strain. Otherwise, the general trends for 5-row and 4-row perimeter PBGA packages are quite similar.

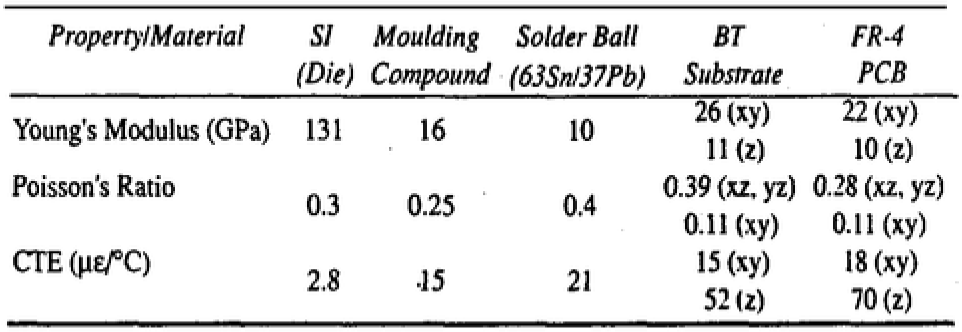
DESIGN FOR RELIABILITY

Based on the results in Figures 4-7, the following concise design rules are recommended for the solder joint reliability of a PBGA assembly:

> **1** For a given package, smaller chip size will enhance the reliability of inner perimeter solder joints but jeopardise thermal balls at the centre. The outer perimeter solder joints are insensitive to the chip size.
> **2** For perimeter PBGAs without thermal balls, thicker BT substrates always improve the reliability of the innermost solder joints. It is especially beneficial for packages with larger chip size.
> **3** For perimeter PBGAs with thermal balls, thicker BT substrates always improve the reliability of thermal balls. The trend of perimeter solder joints with respect to the substrate thickness is insignificant since their plastic strain is considerably less than the thermal balls.
> **4** Without thermal balls, the innermost solder joint of 5-row perimeter PBGA packages has larger plastic strain than that of 4-row ones. However, if thermal balls exist, the difference is minimal.

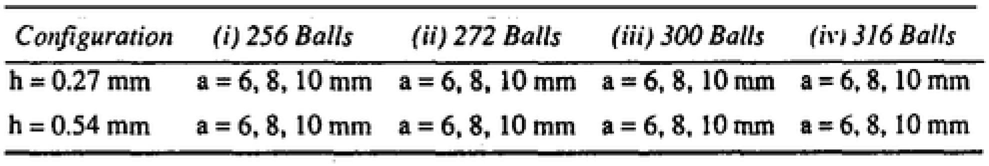
CONCLUDING REMARKS

A series of non-linear computational stress analyses was performed in this study to investigate the solder joint reliability of plastic ball grid array packages with various configurations. The packages under investigation were perimeter PBGAs with and without thermal balls at the centre. In total, 24 cases were studied. The design parameters of concern include solder ball population, chip size, and substrate thickness. The effective plastic strain was evaluated as an index for the reliability of solder joints. Some interesting behaviours were observed. The results of this study were summarised and have led to certain design guidelines for the solder joint reliability of plastic ball grid array packages.



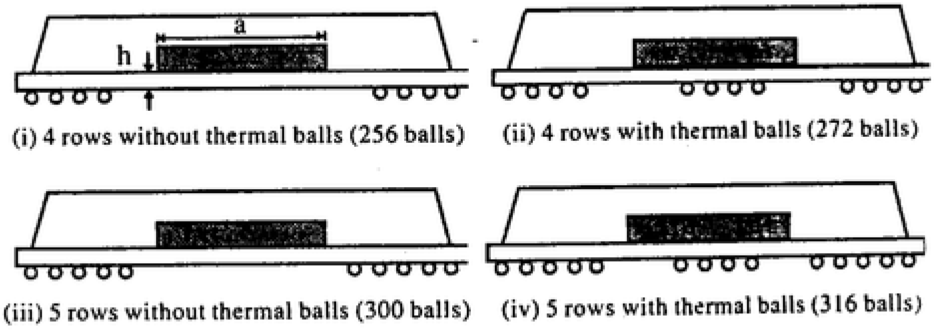
Property/Material	*SI (Die)*	*Moulding Compound*	*Solder Ball (63Sn/37Pb)*	*BT Substrate*	*FR-4 PCB*
Young's Modulus (GPa)	131	16	10	26 (xy) 11 (z)	22 (xy) 10 (z)
Poisson's Ratio	0.3	0.25	0.4	0.39 (xz, yz) 0.11 (xy)	0.28 (xz, yz) 0.11 (xy)
CTE (με/°C)	2.8	15	21	15 (xy) 52 (z)	18 (xy) 70 (z)

Table 1 *Material Properties for Computational Modelling*



Configuration	*(i) 256 Balls*	*(ii) 272 Balls*	*(iii) 300 Balls*	*(iv) 316 Balls*
h = 0.27 mm	a = 6, 8, 10 mm	a = 6, 8, 10 mm	a = 6, 8, 10 mm	a = 6, 8, 10 mm
h = 0.54 mm	a = 6, 8, 10 mm	a = 6, 8, 10 mm	a = 6, 8, 10 mm	a = 6, 8, 10 mm

Table 2 *Configuration of Investigated Cases*



(i) 4 rows without thermal balls (256 balls)

(ii) 4 rows with thermal balls (272 balls)

(iii) 5 rows without thermal balls (300 balls)

(iv) 5 rows with thermal balls (316 balls)

Figure 1 *Various configurations of solder ball population for PBGA package.*

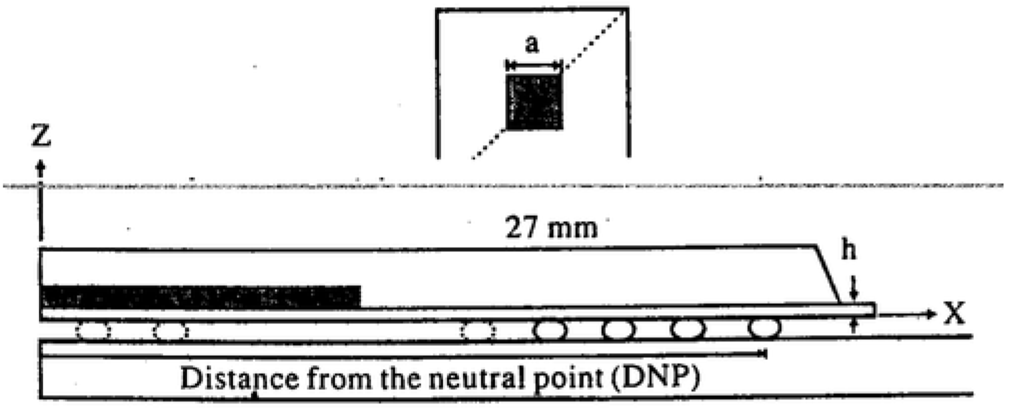


Figure 2 *Schematic diagram of the diagonal cross-section of a PBGA-PCB assembly.*

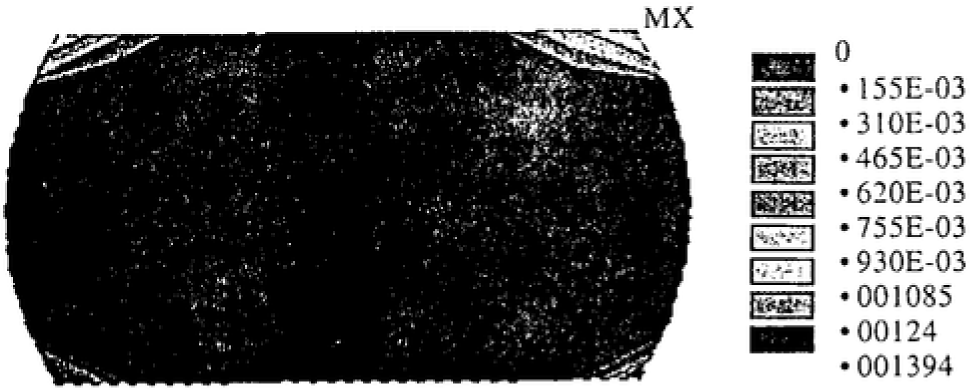


Figure 3 *Typical accumulated effective plastic strain distribution in the solder joint.*

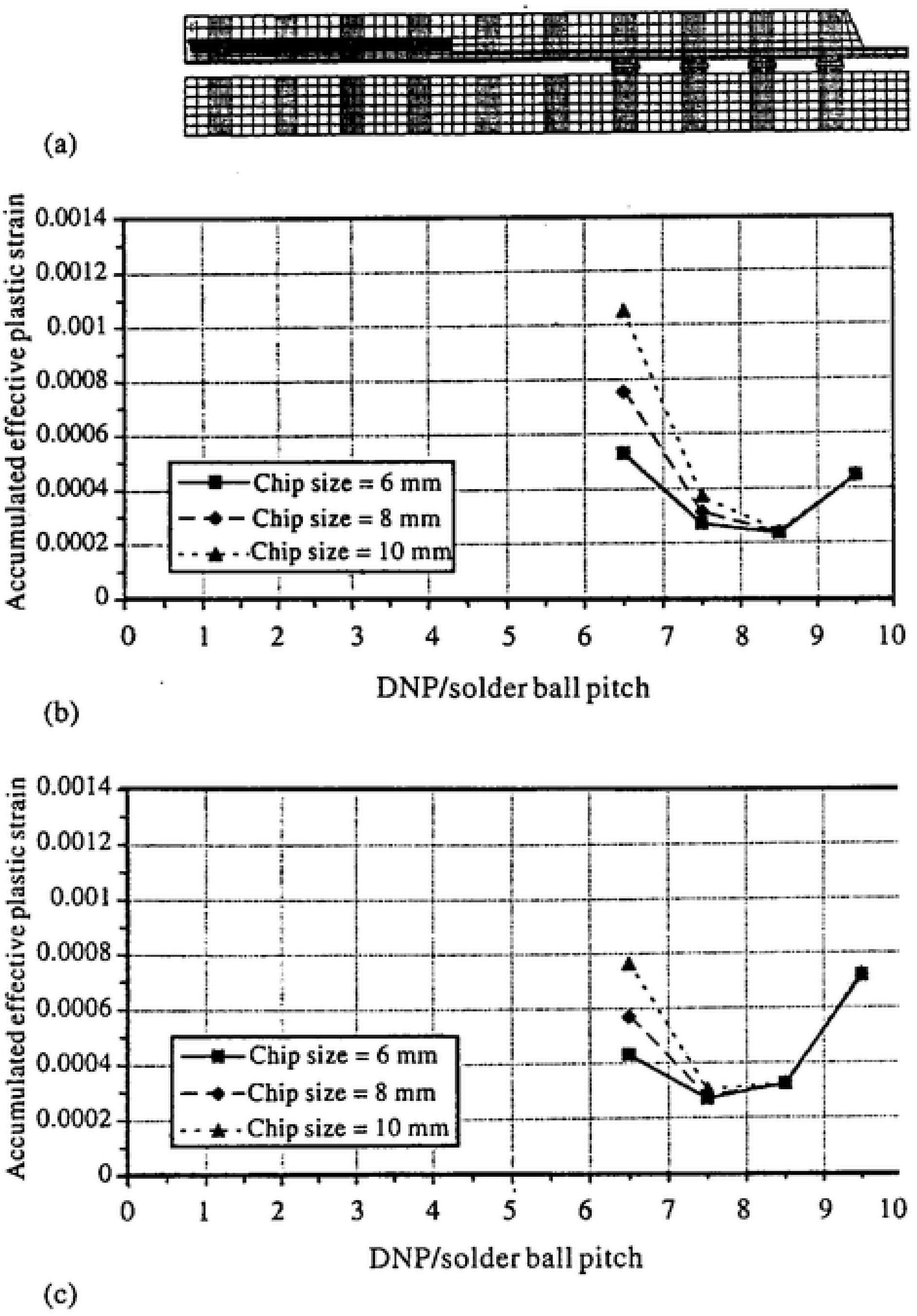


Figure 4 *Numerical results for perimeter PBGA with 256 solder balls. (a) Corresponding finite element mesh; (b) BT substrate thickness = 0.27 mm; (c) BT substrate thickness = 0.54 mm.*

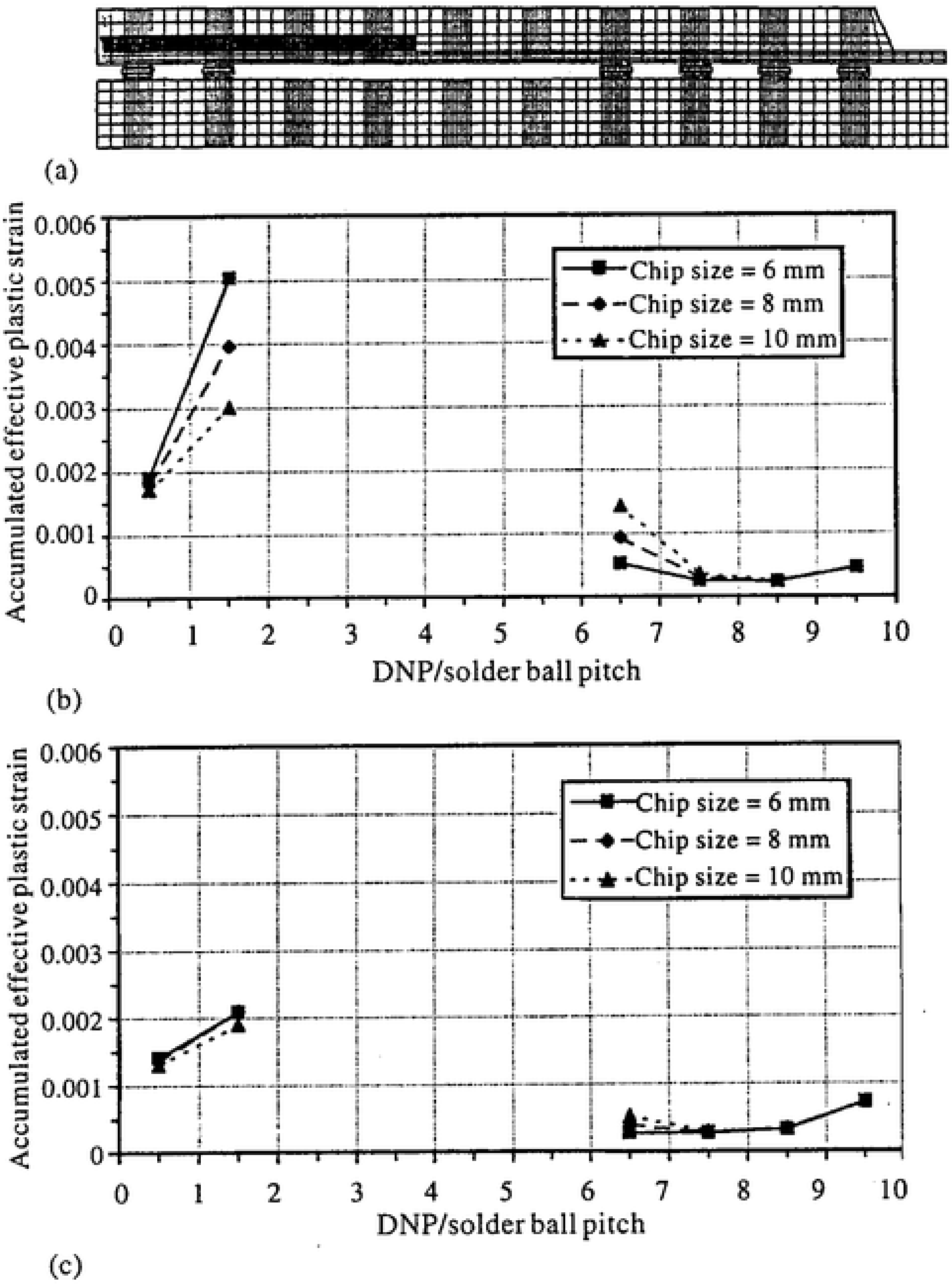


Figure 5 *Numerical results for perimeter PBGA with 272 solder balls. (a) Corresponding finite element mesh; (b) BT substrate thickness = 0.54 mm.*

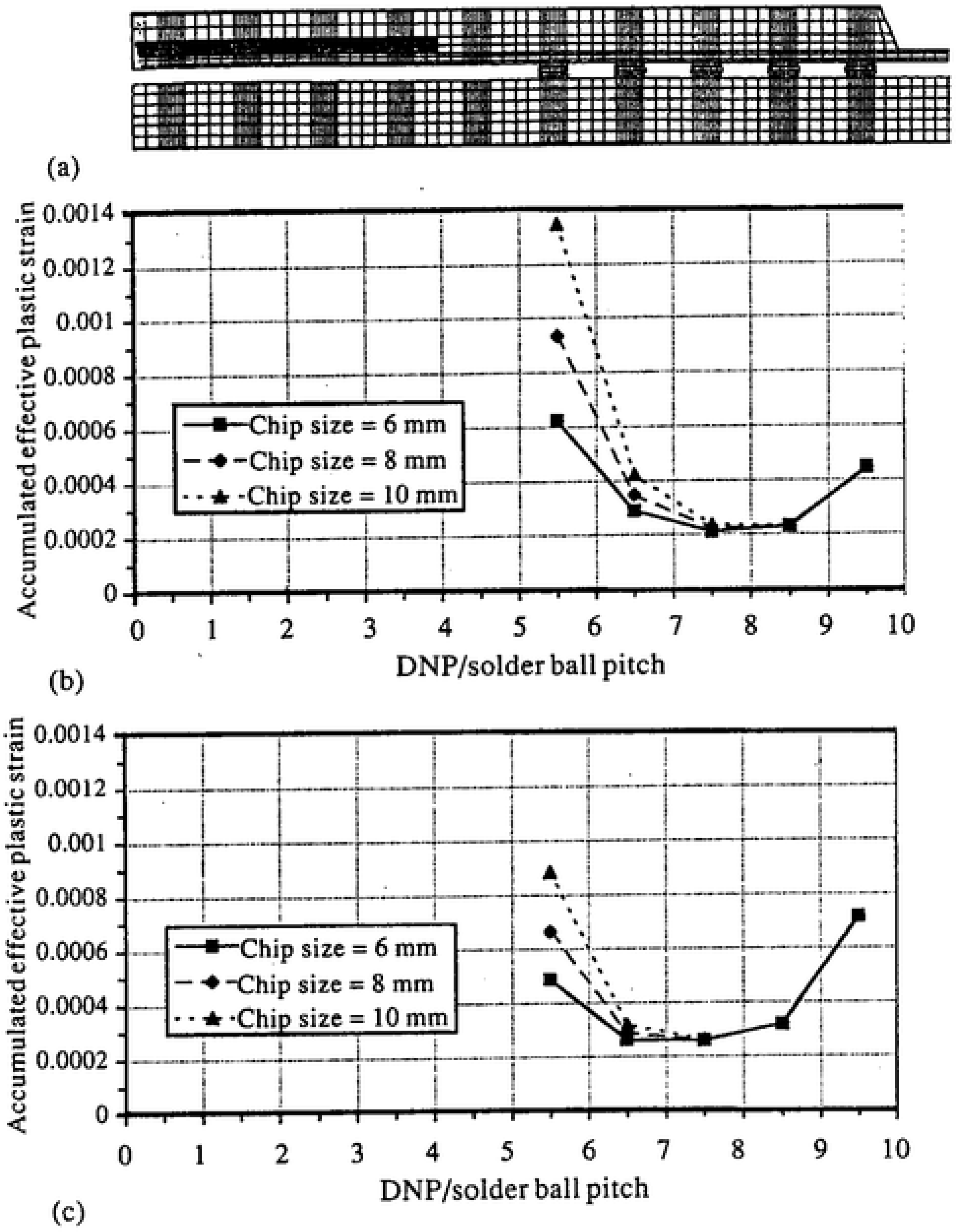


Figure 6 *Numerical results for perimeter PBGA with 300 solder balls. (A) Corresponding finite element mesh; (b) BT substrate thickness = 0.27 mm; (c) BT substrate thickness = 0.54 mm.*

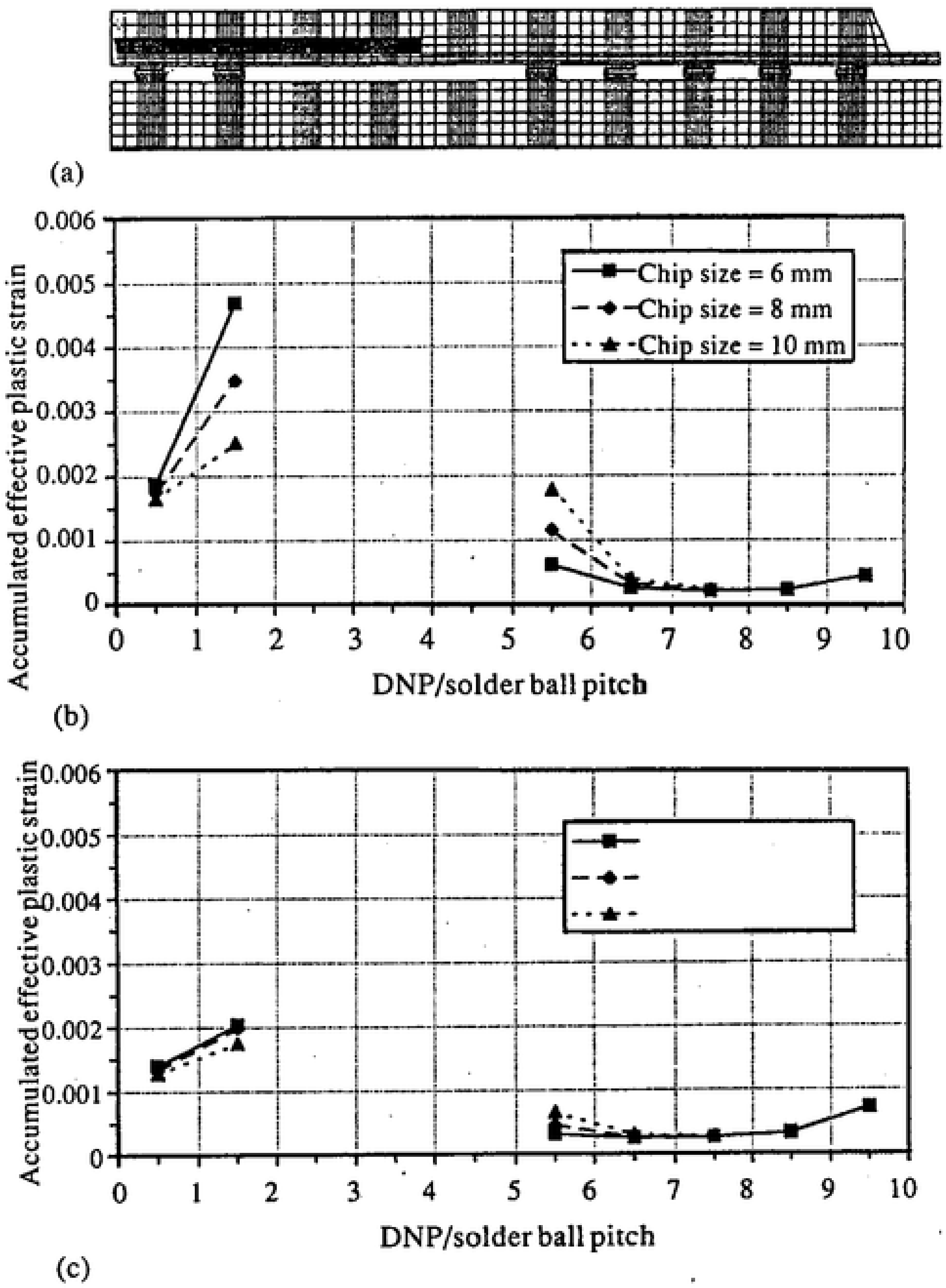


Figure 7 *Numerical results for perimeter PBGA with 316 solder balls. (a) Corresponding finite element mesh; (b) BT substrate thickness = 0.27 mm; (c) BT substrate thickness = 0.54 mm.*

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