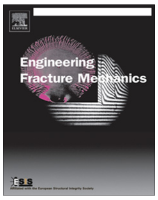
Engineering Fracture Mechanics 187 (2018) 225–240

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech



Predicting delamination in multilayer composite circuit boards with bonded microelectronic components

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ARTICLE INFO

Article history:
Received 8 July 2017
Received in revised form 15 November 2017
Accepted 15 November 2017
Available online 16 November 2017

Keywords:
Composite circuit boards
Microelectronic components
Delamination
Cohesive zone modeling
Finite element analysis

ABSTRACT

The present work developed a mixed-mode cohesive zone model (CZM) with a mode I failure criterion to predict the delamination bending loads of multilayer, composite printed circuit boards (PCBs) assembled with soldered ball grid array (BGA) components that were reinforced with an underfill epoxy adhesive. Two different delamination modes were observed in these microelectronic assemblies: delamination at the interface between the solder mask and the first conducting layer of the PCB, and PCB subsurface delamination at the interface between the epoxy and glass fibers of one of the prepreg layers. The cohesive parameters for each of the two crack paths were obtained from fracture tests of bending test specimens consisting of PCB substrates bonded with the underfill adhesive. The model provided relatively accurate predictions of the crack paths and the bending strength of the actual underfilled BGA-PCB assemblies for a range of adhesive fillet sizes, PCB stiffnesses, and strain rates.

1. Introduction

A printed circuit board (PCB) electrically connects and mechanically supports microelectronic components such as resistors and ball grid array (BGA) packages. Multilayer PCBs are composite laminates consisting of woven glass-fiber epoxy insulating layers and conducting copper layers bonded together under heat and pressure. The copper layers are etched to create the required pattern of conducting traces, and the epoxy of the adjacent insulating layers fills the spaces where the copper was removed, thereby creating copper–epoxy composite conducting layers [1]. Other sites of potential delamination result when an adhesive is used to fill the gap between the underside of a component such as a BGA and the surface of the PCB. The bonds of such "underfill" adhesives act to reinforce the connection with the PCB [2–4].

Interlaminar damage or delamination is one of the main failure modes in PCB composite laminates, because they are much weaker out-of-plane than in-plane. PCB delamination may initiate during the soldering process, particularly with lead-free solders which require higher reflow temperatures than leaded solders [5]. Bending during installation, service and repair can also cause PCB delamination [2,4]. Furthermore, thinner PCBs can be more susceptible to warpage deformation and hence delamination [6] under both thermal and mechanical loading. Therefore, it is important to understand the delamination mechanism and measure the relevant properties governing the process. Cohesive zone models (CZMs) are often used to simulate crack initiation and propagation in both adhesively-bonded joints [7–11] and composite laminates

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https://doi.org/10.1016/j.engfracmech.2017.11.026
0013-7944/

[12–16]. Double cantilever beam (DCB) specimens are frequently used to study delamination and determine the cohesive law parameters in composites laminates [17–19].

Fuchs and Fellner [20] used a CZM to simulate the fracture of mode I DCB specimens made of 0.65, 2, and 5 mm thick PCB adherends. The test specimens were laminated woven glass-fiber prepreg layers containing a Teflon film to form a 20 mm pre-crack. The cohesive parameters were obtained from the 5 mm thick DCBs, and the model was validated by comparing the measured and predicted fracture loads for the other mode-I DCBs. There was a good agreement between the experimental and simulation results. However, the model was not tested for bending delamination in actual circuit boards containing copper layers and microelectronic components.

Schoengrundner et al. [21] used four-point bending to obtain the cohesive parameters for the interface between the prepreg and copper layers in a multilayer PCB. However, the model was not used to make predictions of PCB delamination.

Multilayer PCBs are not homogeneous through their thickness, with conducting and insulating layers of different properties bonded at interfaces that may have different strengths as reflected by the critical strain energy release rate, G_c. In a previous study [22], the present authors showed that underfilled BGA-PCB assemblies under bending always failed in the PCB, and the location of the onset of delamination interface changed with the size of the spew fillet of the underfill epoxy adhesive, and the subsequent crack path followed different interfaces in the multilayer PCBs.

The main aim of the present work was to develop a CZM to predict the initiation and growth of delamination in realistic underfilled BGA-PCB assemblies tested under different bending conditions. Since PCB delamination was the dominant failure mode, the traction-separation parameters of the CZM were obtained from fracture tests of test specimens made from PCBs bonded with the underfill epoxy, without any microelectronic components. The two-parameter CZM was coupled with finite element analysis (FEA) to simulate the delamination and progressive failure in the BGA-PCB assemblies.

2. Experimental methods

This section summarizes the fabrication procedure of the BGA-PCB assemblies as well as the preparation of the fracture specimens. Further details can be found in Ref. [22]. The experiments using various BGA-PCB bending specimens, aimed at determining and predicting the effect of underfill fillet size, PCB stiffness and loading rate, are described in greater detail in Section 2.2.

2.1. Board assembly

BGA packages (iNAND Embedded Flash Drives, SanDisk, Milpitas, USA) with dimensions of 16 × 12 × 0.85 mm having 153 solder balls were assembled on a 1 mm thick printed circuit board (PCB) in a surface mount technology (SMT) development

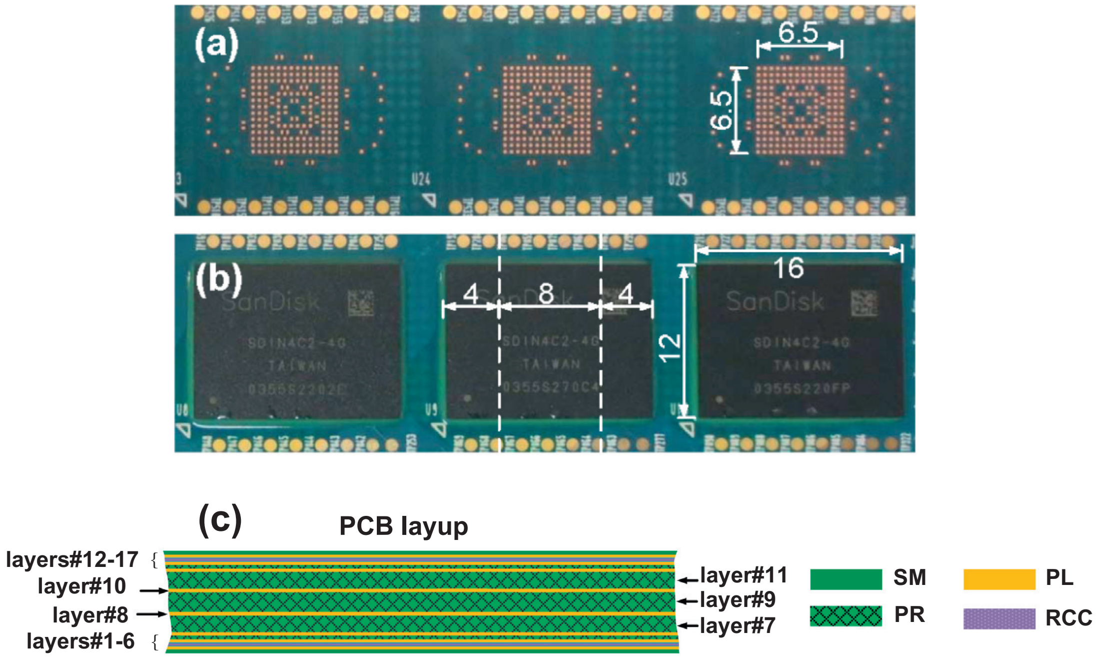

Fig. 1. (a) PCB surface with copper pads before package assembly [22]. (b) BGA packages mounted on PCB. The test specimens were prepared by cutting the BGA-PCB assembly along dashed lines. Dimensions in mm [22]. (c) Schematic of the PCB cross-section revealing different conducting and insulating layers. SM = solder mask, PL = plated copper, RCC = resin coated copper, PR = prepreg [23].