Microelectronics Reliability 72 (2017) 5–17

Contents lists available at ScienceDirect

Microelectronics Reliability

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

Experimental and numerical investigation of flow and thermal effects on flexible printed circuit board

C.H. Lim [a],*, M.Z. Abdullah [b], I.A. Azid [c], M.S. Abdul Aziz [a]

[a] School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia
[b] School of Aerospace Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia
[c] Mechanical Section, Universiti Kuala Lumpur Malaysian Spanish Institute, Kulim Hi-TechPark, 09000 Kulim, Kedah, Malaysia

ARTICLE INFO

Article history:
Received 21 December 2016
Received in revised form 22 March 2017
Accepted 22 March 2017
Available online 29 March 2017

Keywords:
FPCB
Thermal-mechanical FSI
BGA
CFD
Electronic cooling

ABSTRACT

The desire of flexibility, compact, lightweight and low cost in current electronic device increases the application of flexible printed circuit board (FPCB). However, FPCB would encounter significant deflection and stress under operating condition (thermal factor) with air flow cooling system as compared to rigid printed circuit board (RPCB). Therefore, present study aims to investigate the effects of airflow rate and heat on FPCB attached with a ball grid array (BGA) package using experimental and numerical method. In this present study, the simulation was carried out by using FLUENT and ABAQUS, coupled in real time by Mesh-based Parallel Code Coupling Interface (MpCCI) where flow and thermal effects were coupled simultaneously. The experiments were conducted in a wind tunnel with the BGA package on the FPCB. Low discrepancy between simulation and experimental results indicated that the proposed numerical simulation method is proven to be reliable and sufficient to study the FPCB with thermal and flow effects which has not been established by previous researchers. The findings also showed that the Reynolds number and heat have significant effects on FPCB's deflection and stress. Therefore, it is important to include thermal effect when dealing with FPCB under flow environment. The outcomes of this paper can be a guideline to the FPCB industries.

1. Introduction

The high demand of electronic devices has caused the rapid growth of electronic and microelectronic industries where mechanical flexibility is one of the crucial elements. FPCB has gained escalating interest due to its light weight, low cost, more robust, better twistability and flexibility to absorb the stress features [1,2]. Researchers have used FPCB in several applications such as fabricated and mounted flow sensor on the FPCB for heat and flow detection [1,2], flexible wet sensor sheet to detect urination in diapers and applied FPCB in motor, coil and electrodynamics bearings [3–6]. FPCB exhibits higher sensitivity compared to sensor fabricated on RPCB.

Various studies on the reliability of the RPCB with components were conducted where most of the reliability issues on RPCB include bending stress, mechanical shock/drop impact, joints connection and one of the major issues is the thermal stress. Components and IC always produce heat when in operation where different coefficient of thermal expansion (CTE) values of various materials would cause those materials expand in different rate which lead to high stress between materials. The thermal stress is harmful to the RPCB especially interconnection joints. Hence a lot of investigations have been carried out on heat transfer for electronic cooling. The fundamental of the numerical simulation and experimental setup for heat transfer on PCB are built up from those investigations. Thermal cycles were simulated to study the crack initialization and growth in BGA solder joint due to the thermal stress [7]. Besides, Eveloy and Lohan [8,9] investigated the accuracy of computational fluid dynamic (CFD) and performed some experimental investigations to visualize the air flow through RPCB to provide the information such as air flow array, RPCB topology and heat transfer for the CFD studies. Moreover, Grimes and Davies [10–13] performed some experiments to investigate the flow for fan drawing and blowing case studies in the wind tunnel. They highlighted that flow in fan drawing was steady, uniform and easily predictable which could be represented by laminar flow model.

The rigid feature in RPCB becomes constraint in some modern electronic or microelectronic devices. Therefore, FPCB becomes popular and as an alternative to RPCB. The reliability issues on FPCB (i.e. bending stress, mechanical shock/drop impact, joints connection and thermal stress) are similar to RPCB, just that FPCB has better flexibility to absorb more stress/impact as investigated by Chen et al. [14]. There are numerous literatures investigating the mechanical performance, thermal stress and fluid-structure interaction (FSI) of FPCB [15–20]. Previous researches focused more on the thermal stress and cooling effect on the

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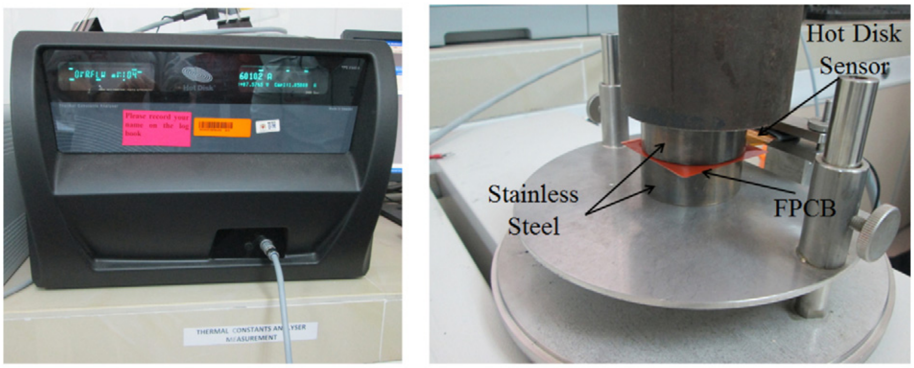
* Corresponding author.
E-mail address: leochlim2@gmail.com (C.H. Lim).

http://dx.doi.org/10.1016/j.microrel.2017.03.022



(a) (b)

Fig. 1. Hot Disk Thermal Analyser (a) TPS 2500 S (b) sensor with setup.

RPCB while deflection and stress induced by flow was often ignored as it is insignificant for RPCB [21]. However, FPCB inevitably confronts more deflection and stress under flow environment compared to RPCB. Therefore, Arruda and Freitas [21] proposed to consider fluid structure interaction (FSI) in FPCB study as the surrounding air could offer external effects to the structure. The importance of utilizing FSI in mechanical performance study of FPCB was stressed by Leong [22]. Leong et al. [23–27] examine the deflection, stress and force induced by air flow with various factors such as component thickness, component size, flow velocity, mounting, misalignment of FPCB and etc. They concluded that flow velocity and misalignment angle have significant effects to the FPCB's deflection and stress. However, the studies were limited to the flow effect on FPCB which did not include thermal effect. In other words, the FPCBs in those studies were in idle state. Besides, various components were simplified as dummy blocks (Perspex) in experiment and simulation which were not a real duplication to the FPCB with operating BGA under flow environment. The model will lose the information on the solder joints and heat transfer information on the BGA package especially the thermal phenomena. According to Amy [28], if component lead or solder joints stresses are required then detailed model are necessary.

In this paper, thermal effect will be included together with flow effect in the studies which was not investigated by previous researchers. The different between this paper and previous investigations are the thermal factor and BGA packages. To elaborate, previous studies only considered flow effect without heat involved on FPCB. Furthermore, with BGA packages involved in present study instead of dummy blocks, the studies are closer to the real case scenario. It is important to consider thermal effect with flow effect simultaneously when dealing with operating BGA attached on FPCB as the responses would be different which will be presented in the result section. Experiments were also conducted using various flow velocities and thermal power to verify the results of numerical method in this paper. The study of FPCB with ball grid array (BGA) packages in operating condition is necessary so that the deflection, stress and thermal effect on FPCB could be controlled and reduced. In order to control those responses of FPCB with operating BGA packages under flow environment, thermal factor should be included and coupled simultaneously with flow effect.

2. Experimental setup

2.1. FPCB thermal and material properties testing

Single-sided FPCB consists of single polyimide and single copper layers with an overall thickness of 53 μm were used in the present study. The thermal conductivity, k and specific heat, C_p of FPCB were obtained using Hot Disk Thermal Constants Analyser TPS 2500 S as shown in Fig. 1. Hot Disk Thermal Constants Analyser employed Transient Plane Source (TPS) technique which met ISO 22007-2 as described in the user manual [29]. During the measurement, the sensor was placed between the surfaces of two FPCB pieces as shown in Fig. 1(b). The k and C_p value were then transferred to computer for display and storage.

The density, ρ of the FPCB was obtained by using Shimadzu Weighing Scale AUW220D with the accuracy of 0.1 mg to measure the mass of the FPCB and divided by the volume of sample. Furthermore, tensile test was conducted to obtain the Young's modulus, E and yield strength, σ_y of FPCB by using INSTRON 3367 Universal Testing Machine at the speed of 0.25 mm/min based on ISO 527-3 [30]. Six tests had been conducted with three specimens cut from FPCB in X - orientation while another three specimens cut in Y - orientation. The properties obtained were used in numerical simulation. Six tests had been conducted for each of the test mentioned in this subsection and the obtained results will be presented in subsection 4.1 with 95% level of confidence.

Table 1
Dimensions, mechanical and thermal properties of the FPCB assembly.

Material		Dimensions (mm)	ρ (kg/m^3)	E (GPa)	Poisson's ratio	k (W/[mK])	C_p (J/[kgK])	α (ppm/K)
FPCB		120 × 120 × 0.053	3839	10.00	0.34	0.3	421	17
BGA package	Copper (Bond pad)	$\Phi = 0.45$	8930	129.93	0.34	398.0	383	16.8
	Lead-free solder joint	Height = 0.35 $\Phi = 0.55$ Pitch = 1.0	7500	52.00	0.34	57.3	250	23
	BT substrate	11.0 × 11.0 × 0.25	1700	26.00	0.39	0.2	920	15
	Silicon die	8.0 × 8.0 × 0.4	2300	130.36	0.28	98.4	721	2.5
	Mold	11.0 × 11.0 × 0.8	1820	16.52	0.25	0.6	236	14.8