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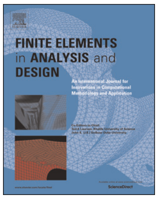

Optimisation of thermo-fatigue reliability of solder joints in surface mount resistor assembly using Taguchi method

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ABSTRACT

The effect of geometric and ambient parameters on static structural integrity of solder joints in surface mount resistor assembled on printed circuit board (PCB) is investigated to improve the thermo-fatigue reliability of the joints and components. The optimisation of resistor thickness (R_T) and components standoff height (CSH) in a range of operating homologous temperature (T_H) is poised to produce optimal assembly which could accumulate least strain energy density (ω_{acc}) in resistor joints and consequently possesses longer cycles to failure (N_f). Taguchi design of experiment (DOE), $L_9(3^3)$, is used to generate nine designs and finite element modelling (FEM) is employed to simulate the responses of the assemblies to reliability influencing factors (RIFs). The Garofalo–Arrhenius constitutive creep relation is utilised to model high-temperature response of the soldered joints while the concept of signal to noise ratio and statistics are used to determine the optimal design. The results show that settings of lowest R_T, highest CSH and T_H of 0.86 produce optimal assembly which demonstrates potential of reducing ω_{acc} and increasing N_f of the best design of DOE by 46.9% and 88.3%, respectively. More results show that the nature of finite element model and difference in magnitude of thermal expansion coefficient (CTE) of two bodies bonded together and which experience the same temperature change determine the degree of damage on the interface with the former being more determining.

The authors propose the model $D_{M/N} \equiv D_{N/M} = \sqrt[3]{K_1 \times K_2} \left\{ \begin{array}{l} 1 \le D_{M/N} \equiv D_{N/M} \langle \infty \\ 1 \le K_1 \times K_2 \langle \infty \end{array} \right.$

(where: M/N, K_1, K_2 are isotropic materials, CTE and geometric ratio, respectively) as a quick tool to rank and compare boundary damage in a multi-isotropic-material joining.

1. Introduction

Resistors remain the key components of most electronic devices which are increasingly deployed to mission critical electronic systems. Such systems operate in sectors which include automotive, oil well-logging and aerospace. In automobiles, electronics are increasingly deployed in the under-the-hood where they serve as sensors and control devices or Electronic Control Unit (ECU). It is anticipated that increase in electronic content of vehicle in response to increasing demand on improving many automobile systems which include engine performance, transmission, steering, traction and combustion, will lead to more electronics being deployed to high-temperature zones of the automobile. Typical under-bonnet and silencer electronics experience temperature cycling outside the “traditional” temperature range from −55/−65 °C to +125 °C temperatures depending on drive duration, location and climate. Johnson et al. [1] reported that under-the-hood electronics and specifically on-engine electronics can experience ambient temperature cycling in the range from −40 to +150 °C.

Electronics used in well-logging experiences identical temperature cycling. Watson and Castro [2] reported that electronic systems and sensors deployed in downhole drilling operations function at temperatures of about 150–175 °C and above 200 °C in deeper well drilling. Characteristic oil well operates at about 150 °C. Parmentier et al. [3] reported that 80% of oil-wells operates below 150 °C with 95% of them functioning under 175 °C ambient temperature. The search for new oil and gas in very deep reserves coupled with subsequent development and completion of high-pressure-high-temperature (HPHT) wells has necessitated operations in higher-temperature ambient. Consequently, development

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Nomenclature

A,B,C	reliability influencing factors
R_T	thickness of resistor
CSH	component standoff height
T_H	homologous temperature
SJs	solder joints
RIFs	reliability influencing factors
PCB	printed circuit board
CEMs	contract electronics manufacturer
FCOB	flip chip on board
ATC	accelerated temperature cycle
CSP	chip scale package
SSFs	static structural factors
T_M	melting temperature
ET_s	excursion temperatures
FIP	fatigue indicator parameter
L	resistor length
W	resistor width
G	shortest distance between pads
PW	copper pad width
BL	PCB length
BT	PCB thickness
$E_{x,y,z}$	Young's moduli (in x, y and z)
$\nu_{\mathrm{xy,xz,yz}}$	Poisson ratios (in xy, xz, yz)
HATC	highly accelerated temperature cycle
$\frac{d\varepsilon_{cr}}{dt}$	creep strain rate
σ	von Mises effective stress
R	universal gas constant.
$u_{(w)}$	displacement in the vertical direction
γ	cubic expansitivity
M,N	component or Material (A, B)
α	coefficient of linear expansion
Δl	change in length
Δw	change in width
Δt	change in thickness
j	RIFs (designated as A, B or C)
n	Number of level in the experiment.
E_j	effect of factor j
F_{jmin}	minimum value of factor j
N_f	number of cycle to failure
L_i	factor level
ECU	electronic control units
HPHT	high-pressure-high-temperature
S/N	signal to noise ratio
FC	flip chip
R103	resistor component model 103
SMCs	surface mount components
WEEE	waste from electrical and electronic equipment
OEMs	original equipment manufacturers
FEA	finite element analysis
FEM	finite element modelling
$\mathrm{IMC_T}$	thickness of intermetallic compound
T_A	ambient temperature
r	number of measurement
y_i	value of the ith measured response
ω_{acc}	accumulated strain energy density
TL	termination length
TT	termination thickness
PL	copper pad length
PT	copper pad thickness
BW	PCB width
PWB	printed wire board
$a_{x,y,z}$	coefficient of thermal expansions (in x, y and z)
$G_{xy,xz,yz}$	shear moduli (in xy,xz,yz)
$C_{1,2,4,4}$	Garofalo creep parameters
ΔT	change in temperature
Q	activation energy
T	absolute temperature
V	volume of material
ΔV	change in volume
D	damage on a material
l	length
w	width
t	thickness
K_1	CTE ratio of two materials
$\bar{j}_i$	mean of S/N ratio
BGA	ball grid array
F_{jmax}	maximum value of factor j
MTTF	mean-time-to-failure
K_2	geometric ratio of two materials

and production of oil and gas from HPHT wells technically demand that the logging tool electronics be protected from extreme temperature and pressure which would otherwise cause conventional logging tool electronics to fail. Thus, these electronics are protected in sondes and cartridges which increase the device weight and pose a challenge to electronics manufacturing miniaturisation trend.

Similar to the automotive engines, aero engines experience high volume of electronics deployment in recent years. Mechanical and hydraulic actuators in aero engine are increasingly being replaced with electronic actuators. Designing and manufacturing electronics which will operate reliably in harsh ambient demands that the design engineer has in-depth understanding of the complex relationship and interactions among electronics materials, structural integrity of electronics assembly and operating ambient temperature to ensure that system properties and functions are preserved over long operating periods.

Continued reliable performance of surface mount electronic components is challenged by the miniaturisation trend in electronics manufacturing. Surface mount resistors of smaller size are being manufactured and assembled on substrates using varied component standoff height (CSH). The CSH is the height between the base of the resistor and the top of the substrate printed circuit board (PCB). It is basically the height of the solder joints in electronic assembly. With suitable CSH and right thickness of resistor, a good solder joint integrity could be achieved in a resistor assembly. Such assembly has potential to operate satisfactorily in a high-temperature and harsh ambient. In addition to miniaturisation trend, harsh operating conditions and specifically high-temperature operations has adverse effect on the reliability of solder joints in electronic devices. In earlier investigation [4] the effect of elevated temperature operations on thermo-mechanical reliability of flip chip (FC) assemblies was studied and the impact on the integrity of FC solder joints was reported. Since the integrity of solder joints in electronic assemblies depends hugely on the geometry of the joints, evaluating the integrity of solder joints in resistor R102 will provide information which could be used to improve its thermo-fatigue reliability.

There are significant amount of published studies on improvement of integrity of solder joints in surface mount components (SMCs) but most of them have focused on joints made of lead based solder alloys. With lead-free solders rapidly replacing the