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Applications of damage models to durability investigations for electronic connectors

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ABSTRACT

Contact forces between terminals of an electronic connector and the corresponding counterparts play an important role on signal transmission. The mated terminal with insufficient contact force might severely raise electrical resistance and induce intermittence or disconnection of current eventually. The contact force of the terminal could decay dramatically after several thousand mating/unmating cycles. Critical plane approaches are adopted to estimate the service life indicating the number of cycles as the contact force of the terminal degrades beneath the certain value in the present study. Damage parameters based on various criteria are evaluated for the terminal under the cyclic loading conditions. Relationships among the damage parameter, the contact force reduction ratio, and the number of cycles are then constructed by linking numerical results to experimental measurements. It is validated that the Smith–Watson–Topper criterion could be successfully applied to the service life assessment of the terminal.

1. Introduction

Contact forces between terminals of an electronic connector and the corresponding counterparts are usually required to be within an appropriate range. Excessively large contact force could cause inconvenience or difficulty of the operation (for example, large insertion force). Insufficient contact force, on the other hand, might severely raise electrical resistance and result in the intermittence or disconnection of transmitted current eventually. For some connectors frequently subjected to the cyclic mating/unmating loading conditions, the contact force of the terminal generally decays dramatically after numerous cycles. Assessments of the service life, which indicates the number of cycles as the contact force of the terminal degrades beneath the certain value, are therefore important for the terminal design. Based on the authors' understanding, senior designers typically utilize permanent deformation of the terminal after unloading process to appraise the service life indirectly. Such scheme nevertheless lacks strong theoretical background and possibly leads to incorrect estimations. A systematic methodology evaluating the service life is thus anticipated and developed in the present study.

In recent years, critical plane approaches have been widely used and successfully predicted the fatigue lives of various structural components under the multiaxial loading conditions (for example, see [1–4]). The critical plane approach of the fatigue analysis originates from the observations of the fatigue crack, which commonly occurs either on the maximum normal stress/strain plane or on the maximum shear stress/strain plane. The material is assumed to fail on the plane accumulating the largest amount of damage based on a given criterion. Failure defined here does not indicate the rupture of the terminal in which cracks possibly exist though. The argument that nucleation and/or growth of the fatigue crack deteriorate load-carrying capacity of the terminal nonetheless coincides with the physical basis of the critical plane approach.

Smith et al. [5] proposed a damage criterion in which the normal strain amplitude and the mean stress effect are included to estimate the fatigue lives. It is worthy to be noted, for ductile materials, the tensile mean stress is usually detrimental to the fatigue lives while the compressive one is beneficial to the fatigue lives. Brown and Miller [6] incorporated the shear strain amplitude and the normal strain amplitude on this shear plane in a damage model to enhance the accuracy of the fatigue life predictions under certain loading conditions. Lohr and Ellison [7] stated that the crack growth propagating through the thickness dominates the fatigue behavior. They therefore suggested a criterion including the shear strain amplitude driving the crack through the thickness and the normal strain amplitude on this shear plane as well. Simultaneously considering contributions of the shear strain amplitude, the normal strain amplitude acting on the shear plane, and normal mean stress acting on this plane to the damage accumulation, Socie and Shield [8] and Socie et al. [9] further modified the Brown and Miller criterion [6] to improve the fatigue life estimations under several proportional and non-proportional loading paths. Fatemi and Socie [10] and Fatemi and Kurath [11] proposed a damage parameter as a function of the shear strain amplitude and the normal stress amplitude on this shear plane. They concluded that the new criterion gives better fatigue life predictions under various out-of-phase loading histories.

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2. Numerical analysis

A battery connector embedded in a cellular phone is chosen to illustrate how damage parameters are employed for the durability investigation here. A widely-used finite-element analysis commercial package ABAQUS [12] is used in numerical simulations. As shown in Fig. 1, only a terminal without a plastic housing is modeled in the analysis. For the sake of numerical convergence without sacrificing much accuracy, the corresponding counterpart can be rationally assumed to be a plate with infinite stiffness. The terminal subjected to the cyclic mating/umating loading conditions as the plate repeatedly moves downwards and upwards in the 3-direction is shown in Fig. 1. Note that the coordinate system is also specified in the figure. Normally the maximum compressive displacement imposed on the terminal is 1.0 mm. Two other values of the displacement, 1.1 mm and 1.2 mm, are also selected in the analysis for comparisons. Restrained regions of the terminal interfered with the plastic housing are confined in all degrees of freedom. Phosphor bronze 5191RH with an assumption of isotropy is adopted for the terminal material. Elastic–plastic behavior and kinematic hardening rule are implemented into the simulation. Young's modulus and Poisson's ratio of phosphor bronze is, respectively, 110 GPa and 0.34, while the associated monotonic stress–plastic strain response is plotted in Fig. 2. However, the cyclic stress–strain relationship of the material not currently available should be used in the present fatigue analysis instead of the monotonic one. However, for some metals, the difference between the cyclic and the monotonic stress–strain curves is not obvious when no significant plasticity is performed on the material (for example, see Bannatine et al. [13]). Experiments show that the terminal exhibits rather limited permanent deformation even under the largest compressive displacement of 1.2 mm, and hence the use of the monotonic stress–strain should be reasonable. A value of the friction coefficient of Coulomb's model employed for all contact surfaces is set to be 0.2. Second-order reduced-integration structure elements are assigned to the analysis model.

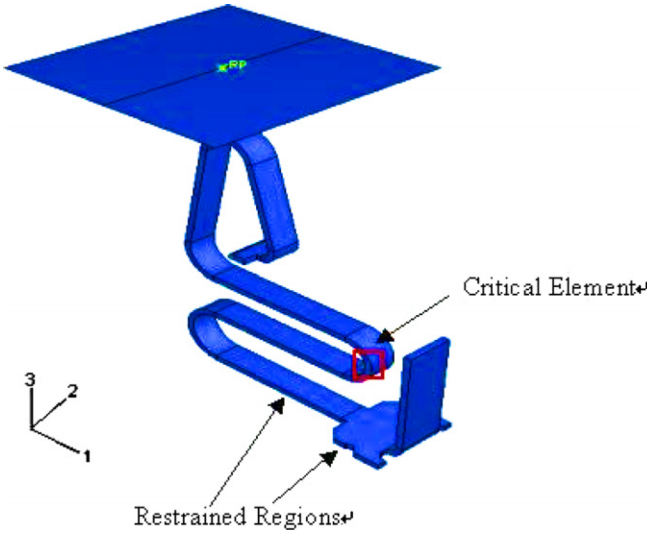

Fig. 1. Analysis models of both the terminal and the plate.

Three damage criteria are employed in the analysis. Both the normal strain amplitude criterion and the Smith–Watson–Topper criterion [5] are categorized as the uniaxial type of criterion, whereas the Brown and Miller criterion [6] the combined normal and shear type of criterion. Damage parameters based on different criteria are evaluated under the cyclic mating/unmating procedures as the stabilized stress–strain hysteresis loops are reached (after 10 cycles in this study). An element having largest von Mises equivalent stress/strain, marked by a square region shown in Fig. 2, is designated as the critical element. Note that the terminal is primarily dominated by the bending moment owning to characteristics of the geometry shape and loading conditions. Stress and strain components of the critical element are then extracted for the computation of damage parameters.

The damage parameter P_{NE} of the normal strain amplitude is defined as

$$P_{\mathrm{NE}} = \varepsilon_{\mathrm{na}} \tag{1}$$

Here $\varepsilon_{\mathrm{na}}$ represents the normal strain amplitude on the certain material plane. Smith et al. [5] introduced the maximum normal stress which achieves in a cycle $(\sigma_n)_{\max}$ into their damage parameter P_{SWT} to account for the mean stress effect as

$$P_{\mathrm{SWT}} = (\sigma_n)_{\max}\varepsilon_{\mathrm{na}} \tag{2}$$

Brown and Miller [6] proposed that both shear strain amplitude γ_{a} and normal strain amplitude on this shear plane are harmful to the fatigue lives. The damage parameter P_{BM} is thus in a form of

$$P_{\mathrm{BM}} = \gamma_{\mathrm{a}} + K\varepsilon_{\mathrm{na}} \tag{3}$$

where a constant K is selected to be 0.5 here.

Searching procedures of the critical plane for all criteria are the same as those reported in Chu et al. [1] and Chu [14]. Initially the stress and strain states of the critical element are expressed on the 1–2, 2–3, and 1–3 planes. The variation of stresses and strains on any other material plane can then be obtained by matrix transformations. For example, as shown in Fig. 3, the shaded 1′-2′ plane is reached by first rotating the 1–2 plane counterclockwise about the 3-axis by an angle θ followed by rotating the current 2–3 plane counterclockwise about the new 1-axis (1′-axis) by an angle φ. The critical plane can then be found by incrementally sweeping the angle θ from 0° to 360° combining with the angle φ from 0° to 180°.

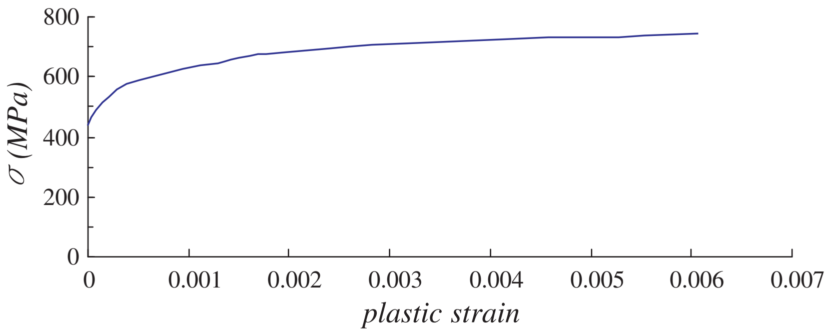

Fig. 2. Relationships between the stress and the plastic strain for phosphor bronze 5191RH.