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DIRECT CYCLIC METHOD FOR SOLDER JOINT RELIBAILITY ANALYSIS

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ABSTRACT

Low-cycle fatigue is a common failure mechanism in solder joints of a BGA in electronics packaging industry. Cyclic thermal loading leads to stress reversals and the accumulation of inelastic strain in the joints. In this paper the direct cyclic technique implemented in ABAQUS [1] has been used to predict the stabilized response of a BGA model subjected to cyclic thermal loading and cyclic bending loading respectively. The results are compared with the classical incremental simulation. Significant performance gains with very good

DIRECT CYCLIC ALGORITHM

The algorithm to obtain a stabilized cycle is described in detail in the following references [1, 9, 10, and 11]. The basis of the direct cyclic method is to construct a displacement solution that describes the response of the structure at all times *t* in a load cycle with period *T*. We use a truncated Fourier series for this purpose,

$$u(t) = u_0 + \sum_{k=1}^{n} u_k^s \sin(2\pi k \frac{t}{T}) + u_k^c \cos(2\pi k \frac{t}{T})$$

where *n* represents number of Fourier terms, u_0, u_k^s and u_k^c are unknown displacement coefficients. We also expand the residual vector into a Fourier series in the same form as the displacement solution:

0 3165. 3- jT)=k(+D $\sum_{k=}^{n}$ 651951. 0 +R_k^c 3 $k\frac{t}{T}$

For comparison purpose the same model is also analyzed using the classical transient analysis. Under cyclic temperature loading, it requires 8 repetitive steps before the solution is stabilized. For the case where it is subjected to cyclic bending loading, it requires 5 repetitive steps before the solution is stabilized.

Figure 2. Temperature cycle.

RESULTS AND DISCUSSIONS

One of the considerations in the design of the BGA assembly is the stress distribution and deformation in the solder joint so that solder fatigue life can be predicted. It is found that maximum occurs in the “toe” area closest to the corner of the BGA assembly. Fig.3 shows the shear stress distributions obtained from the direct cyclic analysis and the classical approach. A comparison of the creep energy dissipation obtained in a direct cyclic analysis with that obtained in a transient approach is shown in Fig.4. A similar comparison of the inelastic energy dissipation obtained using both approaches is shown in Fig.5. A comparison of the evolution of the shear stress versus the inelastic strain obtained using both approaches is shown in Fig.6 for the case subjected to cyclic temperature loading. The shapes of the stress-strain curves and the amount of energy dissipated during the stabilized cycle are similar. So are the peaks and mean values of the shear stress over the stabilized cycle obtained using both approaches. The mean values of the inelastic strains over the stabilized cycle obtained using the approaches are somewhat different. One possible explanation is that when the stabilized cycle is not easily found (for example, when the loading is close to causing ratcheting), the state around which the stabilized solution is obtained may show considerably more/less “drift” than would be obtained in a transient analysis.

A similar comparison of the evolution of the stress versus the plastic strain obtained using both approaches is shown in Fig.7 for the case subjected to cyclic bending loading. The shapes of the stress-strain curves are again similar.

One advantage of using the direct cyclic method, in which the global stiffness matrix is inverted only once, instead of the classical approach in ABAQUS is the cost savings achieved. The saving will be more significant as the problem size increase since the stiffness matrix decomposition will be more expensive for larger problem. For the case subjected to cyclic temperature loading, it took approximately 80,832 CPU seconds to reach a stabilized state for a transient analysis as opposed to 16,833 CPU seconds for a direct cyclic analysis, leading to a factor 4.8 saving in CPU.

Figure 3. Shear stress distribution obtained using classical approach (left) and direct cyclic procedure (right).

Figure 4. Creep energy dissipation obtained using classical approach (left) and direct cyclic procedure (right).

For the case subjected to cyclic bending loading, it took approximately 10,976 CPU seconds to reach a stabilized state for a transient analysis as opposed to 7,308 seconds for a direct to s1.6(i)1.a1g.5( ) of 0.oxigss23 Tc0.s0.6(o C)3.263((appro4.4(cl)-1(itic assumptions for direct cyclic analysis is that we use a global constant elastic stiffness matrix so that the equation system is inverted only once in order to achieve a computational efficiency. For a BGA model subjected to a relatively large bending stress in a relatively flexible structure, geometric nonlinearity becomes important. One of the approaches might be to update the geometry and initial stress stiffness after each iteration, or to take geometric nonlinearity fully into account during the stress/plastic strain recovery. However, none of these has been implemented in ABAQUS for direct cyclic as to date. Therefore, it is expected that the direct cyclic algorithm is likely to perform at a slow converged rate for this kind of flexible structure.

Figure 5. The sum of creep and plastic energy dissipation obtained using classical approach (left) and direct cyclic procedure (right).

Figure 6. Comparison of the evolution of shear stress versus inelastic strain obtained using the direct cyclic analysis (red line) and transient analysis (blue line) approaches.

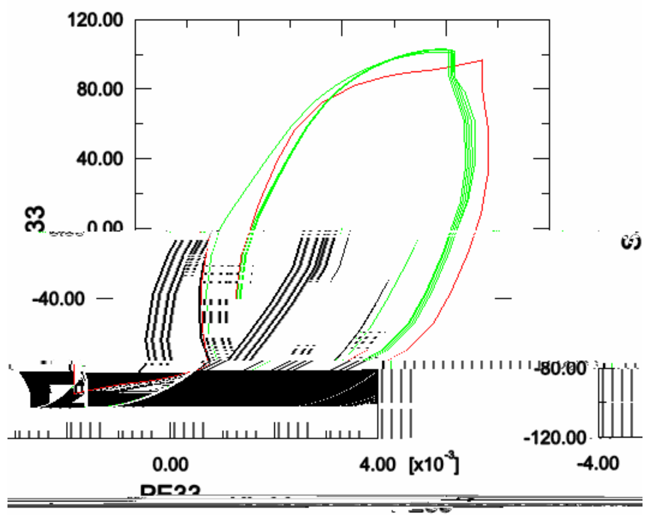

Figure 7. Comparison of the evolution of stress versus plastic strain obtained using the direct cyclic analysis (red line) and classic analysis (green line) approaches.

SUMMARY

The direct cyclic technique implemented in ABAQUS has bee used to predict the stabilized response of a BGA model subjected to cyclic thermal loading and cyclic bending loading respectively. The results are

thermal-mechanical loads by a direct cyclic method" , ABAQUS user conference, 2003.

9. H. Maitournam, B. Pommier, J.J. Thomas, "Détermination de la réponse asymptotique d'une structure anélastique sous chargement thermomécanique cyclique", C.R.Mécanique 330, pp. 703-708, 2002.

10. Q.S. Nguyen, "Stabilité et mécanique non linéaire", Hermès Sciences, 2000.

11. B. Pommier, "Dimensionnement thermomécanique des culasses par la méthode cyclique directe", Thèse de Doctorat de l'Ecole Polytechnique, 2003.