Deformation transfer model of spacecraft solar cell and substrate

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Summary Three-layer deformation transfer model is established by simplifying spacecraft solar cell and substrate multi-layer structure. Considering the layer displacement and stress continuity, we derivate the equations to be distributed within the layers, which is calculated to the basal cell layer of the strain transfer factor. The error of deformation transfer factor is 2.6% contrasting with the finite element simulation results. Based on tri-layer model, we analyze the impact of glue and substrate material parameters to strain transfer factor.

MODELING AND ANALYSIS

Solar cell is the ideal power of spacecraft, and it transforms solar energy to electrical energy by using semiconductor quantum effects. The structure of aerospace solar cell includes cell and substrate which are multi-layer composite structure [1]. In the spacecraft, cells are jointed to substrate using Silicone rubber. In the harsh space environment, the deformation of the substrate and the cell will emerge. Because of the difference of material between the cell and the substrate, the deformation reaching the cell from the substrate is different from that of the substrate. And even it damages the structure of the cell and the substrate.
The multi-layer structure of the cell and the substrate is simplified to three layers which include cell, glue and substrate. Established the tri-layer model considering the continuous conditions, we analyze the impact to strain transfer of some factors. It is helpful to structural optimization and improving the structural reliability.

The deformation transfer model of the cell and substrate

The cell is jointed to the substrate on the silicone rubber. And the cell and the substrate are both multi-layer structure. The cell is composed of germanium, glass, silver etc. In details, there are 1-glass, 2-Silicone rubber, 3-germanium, 4-silver, 5-silicone rubber, 6-polyimide resin, 7-carbon fibre, 8-aluminum honeycomb, 9-carbon fibre. And the substrate is composed of carbon fiber and aluminum honeycomb, cell and substrate structure shown in Fig.1.
In order to explore the deformation transfer of cell and substrate, we simplify the cell structure. The layer of cell is simplified to germanium, and the layer of substrate is simplified to aluminum. The layer of cell and the layer of substrate are jointed together through the silicone rubber. The thicknesses of each layer are h1, h2, and h3, and the width of cell is l. The materials of layers are considered to elastic material in static loading. In the external load, the substrate layer under external N, cell layer and silicone rubber layer are not subject to external forces, axial deformation by the shear layer from the substrate transfer to the cell.

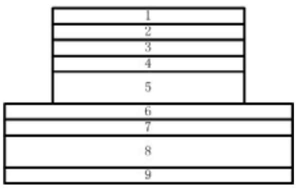

Fig.1. cell and substrate structure

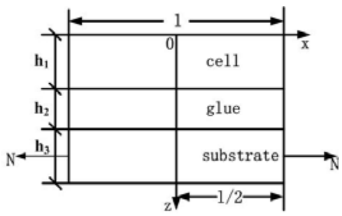

Fig.2. Three-layer model

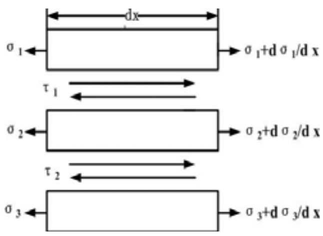

Fig.3.stress analyze of three-layer model

The balance equations can be obtained from Fig.3. And according to the principle that the interlayer shear stress delays, we make the assumptions that lateral displacement and the z- coordinate are into a quadratic relationship. Considering the displacement and stress continuity between layers, we obtain the following equation.

$$T_1 \frac{d^2(\varepsilon_1 E_1)}{dx^2} h_1 - T_2 \frac{d^2(\varepsilon_3 E_3)}{dx^2} h_3 - \frac{1}{E_1} + \frac{h_1}{h_2 E_2}(\varepsilon_1 E_1) - \frac{h_3}{h_2 E_2}(\varepsilon_3 E_3) + \frac{h_3}{h_2} N = 0$$

$$T_3 \frac{d^2(\varepsilon_1 E_1)}{dx^2} h_1 - T_4 \frac{d^2(\varepsilon_3 E_3)}{dx^2} h_3 + \frac{1}{E_1} + \frac{h_1}{h_2 E_2}(\varepsilon_3 E_3) + \frac{h_3}{h_2 E_2}(\varepsilon_1 E_1) - \frac{h_3}{h_2} N = 0$$

The equations can be solved only ε_1 and ε_3 two unknowns, and equations for the 2-order ordinary differential equations, with four boundary conditions. In this paper, we find the numerical solution of boundary value problems by MATLAB.
In order to verify the accuracy of three-layer model, the results are compared to the finite element simulation results. Set the strain of cell layer ε1, set the strain of substrate layer ε2, the strain transfer factor K, namely K = ε1/ε2, which describes the deformation transfer capacity of the substrate to the cell. In the model, the strain

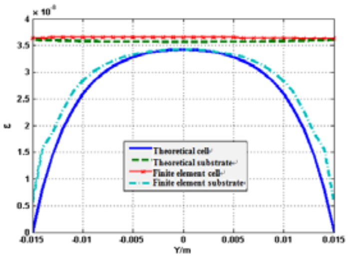

Fig.4. the strain distribution of three-layer model and finite element model

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transfer factor K_t of the three-layer model is 0.959. And the strain transfer factor K_f of finite element simulation is 0.937. Therefore, we can get relative error η of 2.3% of three-tier model and finite element simulation results.

The analyze of factors affecting deformation transfer based on the three-layer model

The establishment of the three-layer model, we have different materials and different sizes of cell the deformation transfer factor analyzed. Firstly, we analyze the effects of the thickness of silicone rubber to strain transfer factor in the specified material and size of the cell and substrate.

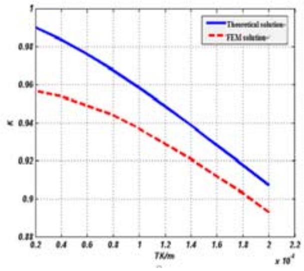

Fig.5. K-TK

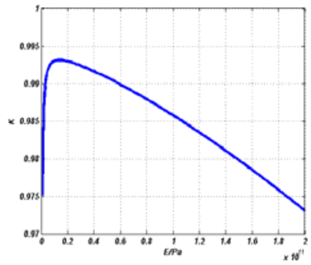

Fig.6. K-E

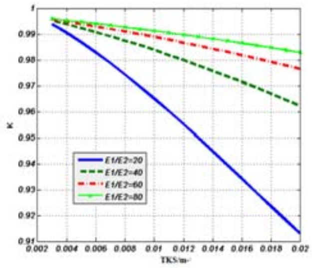

Fig.7. K-TKS

Fig.5 shows the curve of strain transfer factor K and the layer thickness TK, and compared with ANSYS simulation results. In the figure 5, the strain transfer factor increases when the thickness of silicone rubber decreases, indicating that the thicker the silicone rubber, the more difficult the deformation of the substrate to the cell. In order to obtain the better deformation transfer, we can appropriately decrease the thickness of the silicone rubber.

Fig.6 is the curve of strain transfer factor and elastic modulus fixed the thickness of the silicone rubber. K increases with E in the beginning. When E reaches a certain critical value, K decreases with the increase of E. It indicates that there is an optimization of the silicone rubber elastic modulus to make the deformation of the substrate to the cell largest when the parameters of the substrate and the cell are determined.

We analyze the impact of the substrate material parameters to strain transfer factor in addition to the parameters of the silicone rubber. Figure 7 is a diagram of K and substrate thickness TKS fixed cell and silicone rubber material parameters containing the substrate elastic modulus E1 and the silicone rubber elastic modulus E2. In the Fig.7, the elastic modulus of the substrate is that of the rubber of 20 times, 40 times, 60 times and 80 times. From the figure we can see that strain transfer factor K increases with the decrease of the substrate thickness, indicating that in order to obtain better transmission effect, we should try to choose a thinner substrate. At the same time, we conclude that certain material parameters in the layer, the greater the substrate elastic modulus, deformation transfer, the better from different modulus of elasticity contrast curve.

CONCLUSIONS

By simplifying the model, we establish three-layer deformation transfer model of the cell and the substrate, satisfying the stress continuous situations. Considering shear lag interlayer, we get the strain distribution equations. By solving them, we can get the strain distribution interlayer. Compared to the ANSYS simulation results, we conclude that the three-layer model can simulate the distribution of strain interlayer very well with the relative error of 2.3%. Based on the results of three-layer model, we should reduce the thickness of silicone rubber, reduce the thickness of the substrate and increase the elastic modulus to get the better deformation transfer. Best elastic modulus of the silicone rubber is certain when the parameters of the cell and the substrate are certain.

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