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TRIANNUAL REPORT

on the

DESIGN, ANALYSIS AND TEST VERIFICATION OF ADVANCED ENCAPSULATION SYSTEMS

For Period Ending

30 November 1982

Contract 955567

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The JPL Flat-Plate Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

TABLE OF CONTENTS

Section 1.0

SUMMARY

A preliminary reduced variable master was constructed for pressure loading. A study of cell thickness versus cell stress was completed. Work is continuing on encapsulation of qualification modules. A 4' x 4' "credit card" construction laminate was made.

Section 2.0

INTRODUCTION

The objective of this program is to develop analytical methodology for advanced encapsulation designs. From these methods design sensitivities will be established for the development of photovoltaic module criteria and the definition of needed research tasks.

The program consists of four phases. In Phase I analytical models were developed to perform optical, thermal, electrical and structural analyses on candidate encapsulation systems. From these analyses several candidate systems were selected for qualification testing during Phase II. Additionally, during Phase II, test specimens of various types will be constructed and tested to determine the validity of the analysis methodology developed in Phase I.

During Phase III the following items will be covered:

1. Correction of identified deficiencies and/or discrepancies between analytical models developed during Phase I and relevant test data obtained during Phase II of the above contract.

2. Improvement and extension of prediction capability of present analytical models.

3. Generation of encapsulation engineering generalities, principles, and design aids for photovoltaic module designers.

From these items the sensitivity of module performance to various material properties will be determined. This study will enable the intelligent direction of research into assessment of module life potential by analyzing those materials and their properties which through aging would most influence module performance.

In Phase IV a finalized optimum design based on knowledge gained in Phases I, II and III will be developed and delivered to JPL.

Section 3.0

TECHNICAL DISCUSSION

3.1 PRELIMINARY PRESSURE LOADING MASTER CURVE

A preliminary reduced-variable master curve has been constructed. Figure 1 shows this curve. This analysis can be generalized to any pressure loading, structural panel modulus and thickness, and pottant thickness and modulus. The cells must be 4" x 4" and 10 mils thick. The user must first determine the maximum stress in the structural panel dimension, and support condition. The procedure for using the master curve follows:

1. Determine max. stress in the structural panel (Note: use JPL curves or other analysis).

2. Compute $(t/E)\frac{1}{M_T{}^3}$.

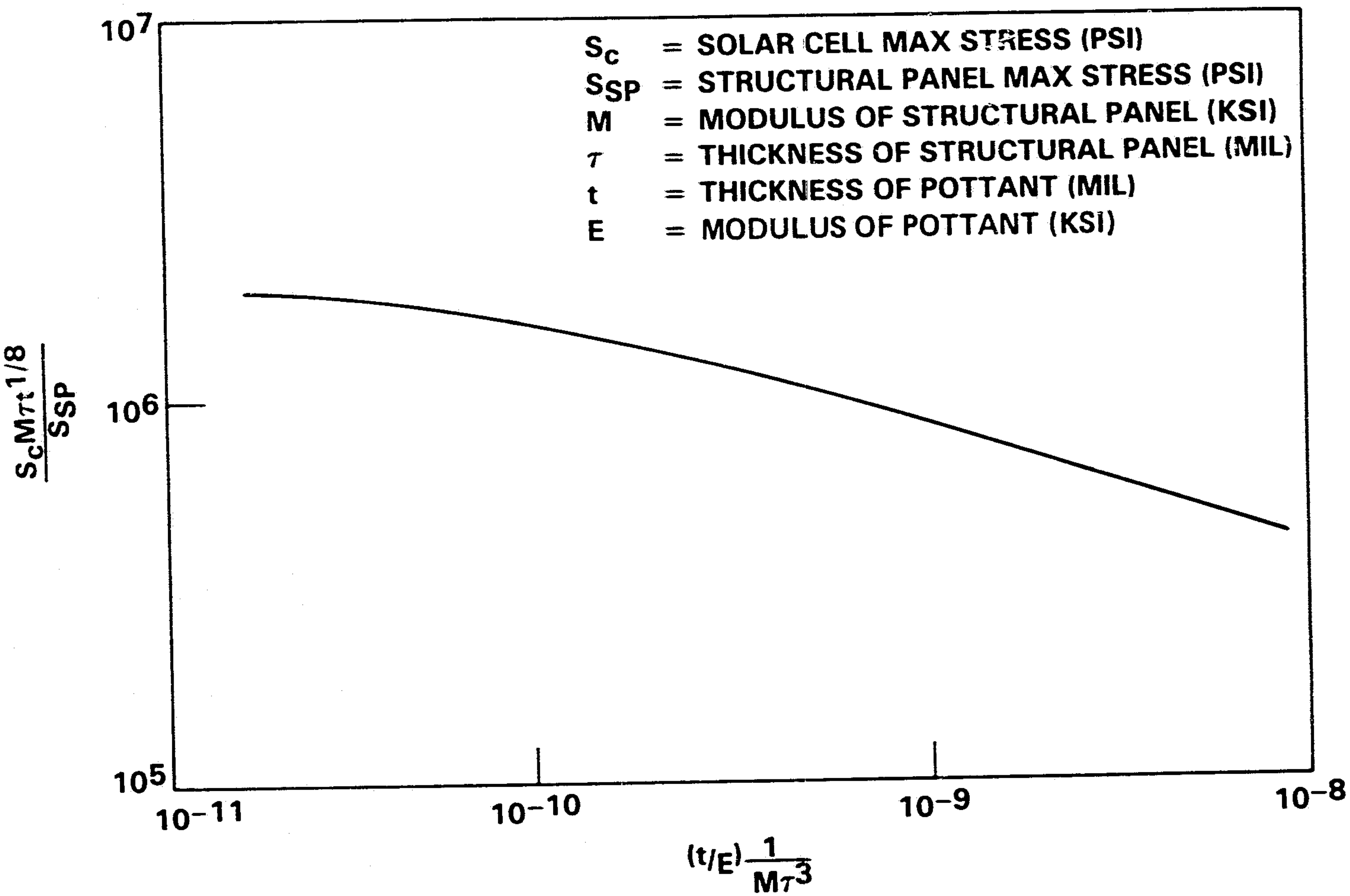
3. Use master curve to determine value of $\frac{S_c M_T t^{1/8}}{S_{sp}}$ where S_{sp} = max. stress in structural panel.

4. Calculate cell stress, S_c.

This curve can be used in conjunction with those presented in Appendix A "Cell Stress Sensitivity to Cell Thickness." Work is continuing on integrating all parameters into a single master curve.

Figure 1

MASTER CURVE FOR PRESSURE STRESS ANALYSIS



3.2 AR COATING SENSITIVITY STUDY

Several additional optical computer runs were done to augment the index of refraction study shown in the July 1982 report with non-optimum AR coating thicknesses. Figure 2 shows the results of these runs. n_c and n_p are the indices of the cover layer and pottant, t* is the optimum AR coating thickness.

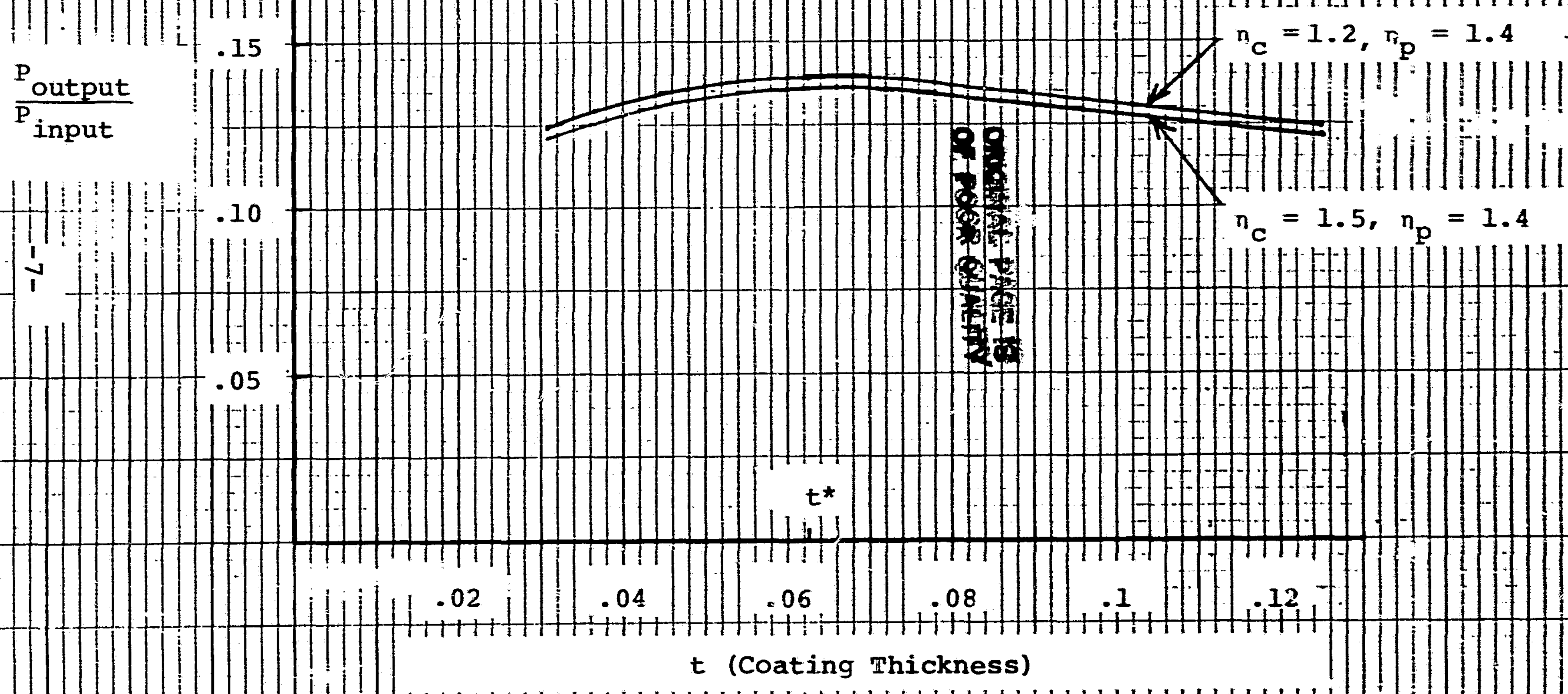
3.3 MODULE CONSTRUCTION

A 4' x 4' laminated "credit card" was made of scrap cells using the 4' x 4' laminator at JPL (constructed by Dale Burger).

The laminator heat source is a silicon heating blanket on which is placed a metal sheet. A 4' x 4' x 1/8" tempered glass sheet is on top of the sheet. The layup was then made as follows:

1) Craneglas 230
2) Acrylar (primed)
3) Craneglas 730
4) EVA A9918
5) Cells (face down)
6) Craneglas 230
7) EVA A9918
8) Craneglas 230
9) Acrylar
10) Craneglas 230

Figure 2



RATIO OF POWER INPUT TO POWER OUTPUT VS. AR COATING THICKNESS

The top and bottom layers of Craneglas are for air removal and do not become part of the lamination. It was found that these Craneglas layers cause the Acrylar to be textured which may be a disadvantage.

A second laminated module "credit card" was made using 121 of the previously manufactured 4" x 4" cells. 10 mil thick FEP Teflon sheets were used against the Acrylar layers. Cosmetic defects on the Acrylar may have been caused by these sheets. TFE Teflon film has been ordered to replace the FEP. TFE has a higher heat deflection temperature and should work better.

Wood substrates were prepared using strips of Type 20CP3110 Schotch Par. This is a .002" thick white polyester film. The results were better than those obtained with full width material.

Section 4.0

CONCLUSIONS AND RECOMMENDATIONS

There are no conclusions and recommendations for this period.

Section 5.0

PLANNED ACTIVITIES

During the next period construction of the qualification modules will continue. Work on a NASTRAN electrical model will start.

Appendix A

CELL STRESS SENSITIVITY TO CELL THICKNESS STUDY

Introduction

Structural analyses were performed to assess the sensitivity of silicon solar cell stress to cell thickness. The stresses in 5 mil and 15 mil cells were determined for glass and steel load-bearing layers and pottant thicknesses of 1, 5, 15, and 20 mils. The thicknesses of the steel and glass were 0.08 inch and 0.125 inch respectively. In every case, the pottant modulus of elasticity was 1000 psi. Two structural loading conditions were studied: (a) a uniform temperature excursion of 100°C, and (b) an imposed deflection to simulate 50 psf uniform pressure. Linear behavior and temperature-independent material properties were assumed. The analyses utilized the MSC/NASTRAN structural analysis computer program. The finite-element structural models used in the present analysis are similar to those described in the Phase 1 Report of the Encapsulation Program (see reference).

Conclusions

For both temperature excursion and pressure loading, cell stress increases as cell thickness decreases. For a pottant thickness of 5 mils, the cell stress approximately doubles when the cell thickness decreases from 15 mils to 5 mils. The cell stress for 10 mil cells is about halfway between the stress for 5 and 15 mil cells. Consistent with the previous results (see Phase 1 report), cell stress decreases as pottant thickness increases.

Discussion

The results of the analyses are summarized in the curves of Figures 1 through 4. Figures 1 and 2 show cell stress for a uniform temperature excursion of 100°C for glass and steel load bearing layers, respectively. Figures 3 and 4 give cell stress for uniform pressure loading of 50 psf. In addition, computer generated plots of deflection for thermal and pressure loading are shown in Figures 5 and 6.

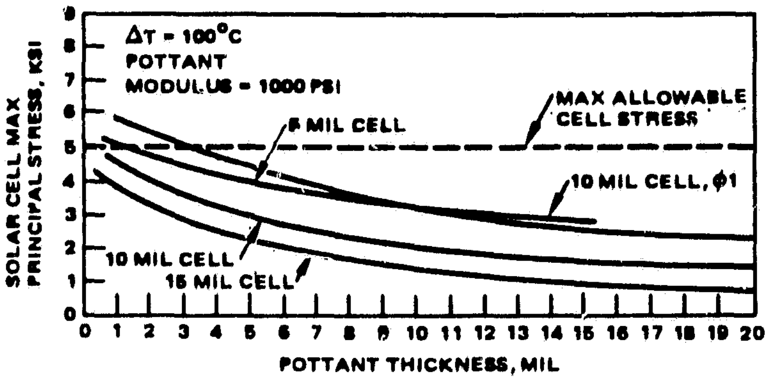


Figure 1. Cell stress versus pottant thickness for a 100°C temperature excursion (glass superstrate modules).

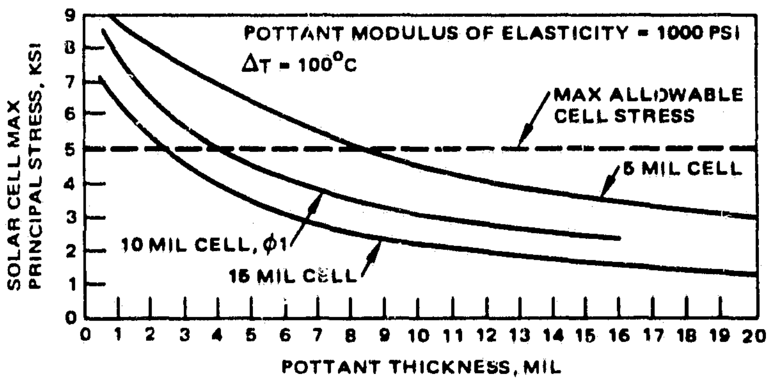


Figure 2. Cell stress versus pottant thickness for a 100°C temperature excursion (steel substrate module).

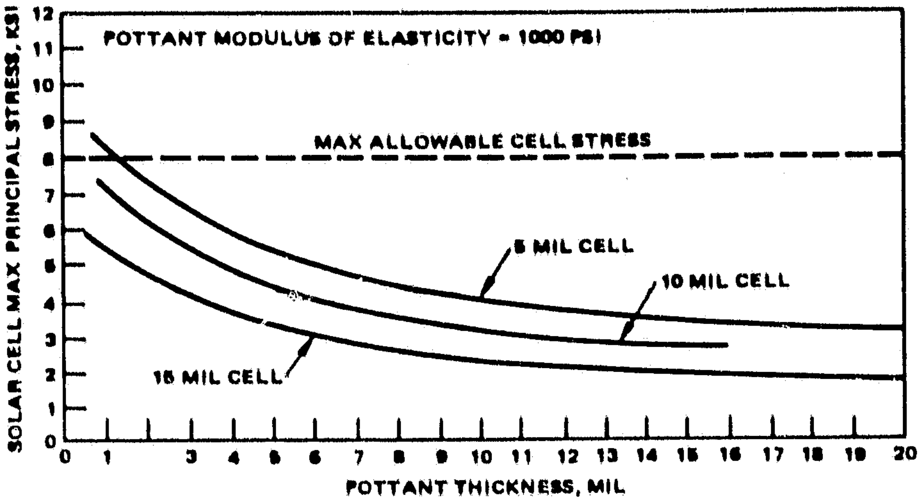


Figure 3. Cell stress versus pottant thickness for 50 psf uniform pressure load (tempered-glass superstrate module).

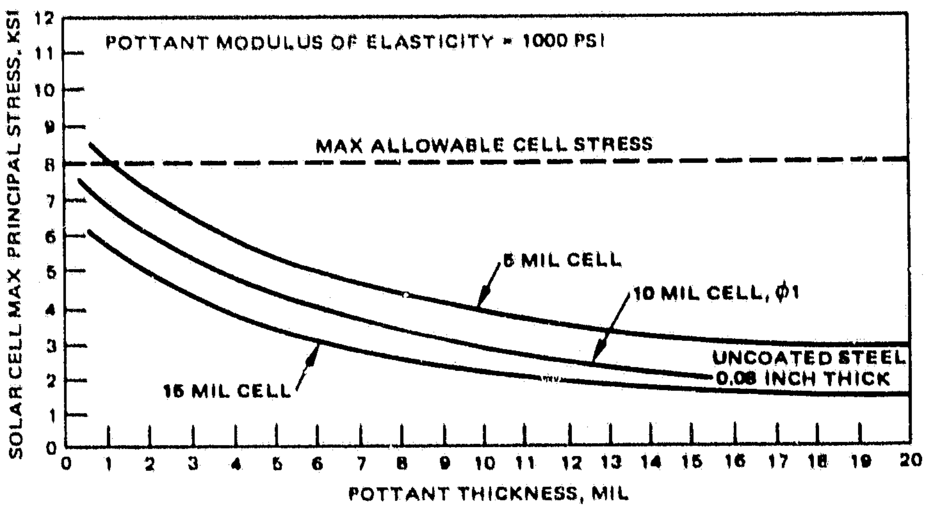


Figure 4. Cell stress versus pottant (E = 1000 psi) thickness for 50 psf uniform pressure load (steel substrate module).

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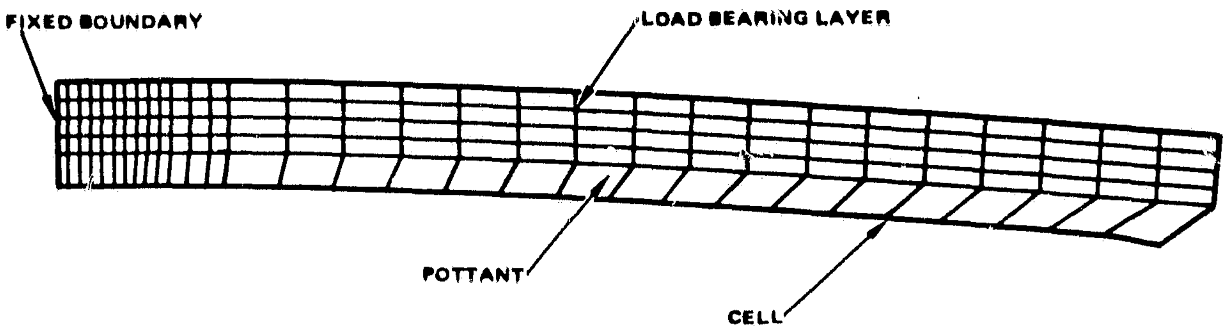

Figure 5. Deflection of load bearing layer, pottant and cell for $100^{o}C$ temperature excursion.

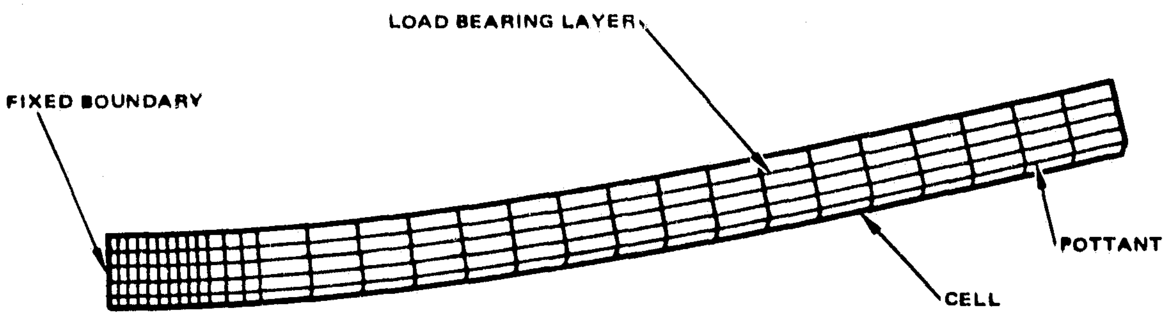

Figure 6. Deflection (due to uniform pressure load) of load bearing layer, pottant, and cell showing transverse shear deformation of pottant.

In Figure 1, it is seen that the stress for a 5 mil cell is about twice that for a 15 mil cell. Assuming a thermal stress design allowable of 5000 psi (see Appendix A, Phase 1 Report), approximately 4 mils of pottant is required to prevent cell failure. For 10 and 15 mil cells, pottant thicknesses less than 1 mil are acceptable.

Note that the curve from the Phase 1 analysis does not match the curves of the present analysis. In the present analysis, the finite element model consisted of the load bearing layer and the cell with pottant between the two. In the Phase 1 analysis, pottant was on both sides of the cell (fully encapsulated) and an aluminum foil cover was included. Both of these elements increase cell stress.

Figure 2 shows cell thermal stress for a steel, load-bearing layer. For pottant thicknesses greater than 5 mils, the 5 mil cell stress is about 2 times greater than the 15 mil cell stress. Approximately 9 mils of pottant is required to prevent cell failure.

Figures 3 and 4 show cell stress for 50 psf uniform pressure loading of glass and steel load bearing layers. A maximum allowable stress of 8000 psi is assumed. It is seen that cell stress is slightly less sensitive to cell thickness when compared to a 100°C temperature excursion. For either glass or steel, 2 mils of pottant is sufficient to preclude cell failure.

Typical deflection plots for temperature excursion and imposed vertical deflection are shown in Figures 5 and 6, respectively. In both plots, the shear flexibility of the pottant layer is apparent. The transverse shear and thickness stretch flexibilities of the pottant reduce cell stress.

Analysis Approach

The analysis approach was identical to that used in Phase 1 of the Encapsulation Program. A two-dimensional finite element MSC/NASTRAN model, shown schematically in Figure 7, was developed. The model consists of rectangular plate elements with symmetric boundary conditions along the center of the cell and free-edge conditions along an imaginary cut plane between adjacent cells.

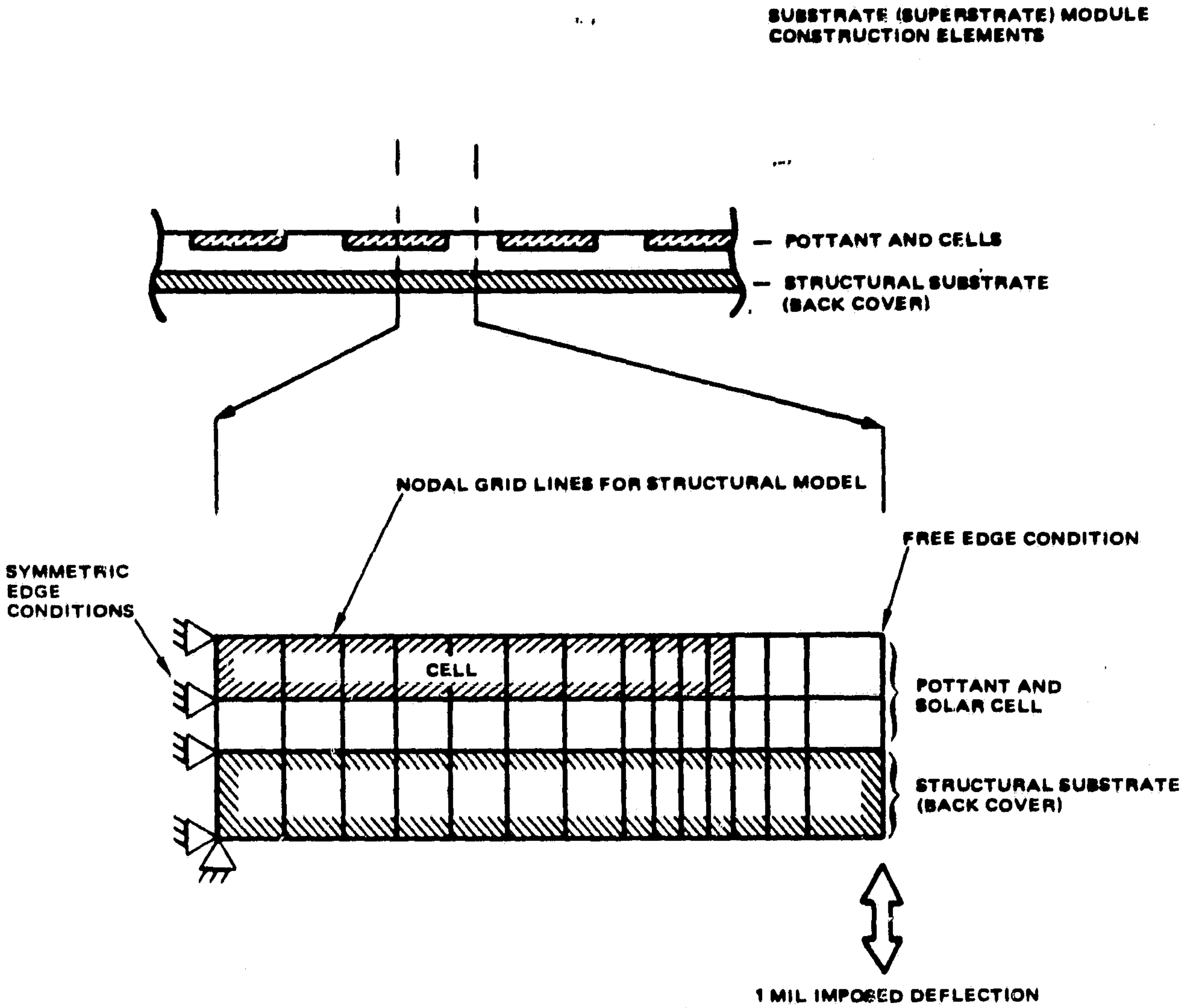

Figure 7. Finite-element structural model for determination of stresses in module construction elements in vicinity of a centrally-located cell. Stresses are due to normal pressure load on module surface.

In this analysis, pottant was included only between the cell and the load bearing layer, whereas in the Phase 1 analysis, the cell was fully encapsulated. This model can be viewed as a cantilever beam with the left-hand edge considered fixed and non-rotating.

Temperature-invariant material properties (evaluated at 25°C) were used in the thermal-stress studies. However, it is known that the pottant modulus of elasticity increases with decreasing temperature. Since the intent of this analysis was to predict trends, the assumption of temperature-invariant properties was deemed acceptable.

For the pressure loading studies, a one mil vertical displacement (as indicated by the arrow in Figure 7) is imposed on the extreme right end of the load-bearing member, and the resulting strains in both the cell and the load-bearing member are then determined. The ratio of the strain in the cell to the strain in the load-bearing member is assumed to remain invariant with deflection of the load-bearing member. On the other hand, this strain ratio is a function of both pottant thickness and modulus of elasticity. The cell stress is then determined by multiplying the strain ratio by the appropriate stress in the load bearing member.

The material properties used in this analysis are listed in Table 1.

TABLE 1. MATERIAL PROPERTIES

Material	Young's Modulus ($lb/in.^2$)	Poisson's Ratio	Thermal Expansion Coefficient ($in./in./^oC$)
Glass	10×10^6	0.22	9.2×10^{-6}
Steel	30×10^6	0.30	10.8×10^{-6}
Pottant	1000	0.40	100×10^{-6}
Cell	17.1×10^6	0.29	4.68×10^{-6}