NASA Technical Memorandum 81866

NASA-TM-81866 19800021263

PHOTOELASTIC TESTS ON MODELS OF THERMAL PROTECTION SYSTEM FOR SPACE SHUTTLE ORBITER

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August 1980

NASA
National Aeronautics and
Space Administration

Langley Research Center
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PHOTOELASTIC TESTS ON MODELS OF THERMAL PROTECTION SYSTEM FOR SPACE SHUTTLE ORBITER

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SUMMARY

The thermal protection system (TPS) of the space shuttle orbiter vehicle, consisting of ceramic tile/adhesive/strain isolation pad/adhesive/aluminum substructure, was modeled photoelastically. A highly sensitive photoelastic material was used in the models to show the nature of the stress-transfer between the strain isolation pad (SIP) and the ceramic tile through the RTV-adhesive layer. Isochromatic fringe patterns were obtained for models subjected to tension and combined tension and bending.

Tests indicated that the load-transfer between the SIP and the photoelastic material occurred at discrete locations causing stress concentrations in the photoelastic material. Stress concentration factors of the order of 1.9 were measured, but as the observed photoelastic response was an integrated effect through the model thickness, the local stress concentration factors at the SIP/tile interface could be even higher.

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INTRODUCTION

The space shuttle orbiter vehicle is basically an aluminum structure insulated from reentry heat over much of its surface by reusable ceramic tiles bonded to nylon felt pads using a room temperature vulcanizing adhesive RTV 560. The tile/pad assemblage is in turn bonded to the aluminum structure again using RTV 560. The pads have low shear stiffness and act as strain isolation pads (SIP) isolating the brittle tiles from thermal and mechanical strains in the aluminum structure. The flatwise ultimate tensile strengths of the ceramic tiles, the SIP, and the total thermal protection system (TPS), i.e. ceramic tile/RTV/SIP/RTV/aluminum have been determined experimentally. Figure 1, taken from reference 1, shows the various components of a flatwise tension test of the TPS. It was found by Rockwell that the ultimate strength of the individual components, the ceramic tile, RTV, and SIP considerably exceeded the ultimate strength of the combined system as shown in Table 1. When the TPS was tested as a system in flatwise tension, failure generally occurred in the tile at the tile/SIP interface as shown in Figure 2. The SIP is composed of a mat of fibers lying in a plane and held together by discrete bundles of transverse fibers as shown in the scanning electron photomicrograph in Figure 3, taken from reference 2. These transverse fiber bundles are composed of inplane fibers pulled through the mat by barbed needles during manufacture of the pad. The reduced strength of the system was attributed to stress concentrations at the SIP/tile interface caused by discrete load transfer across the SIP occurring mainly at the fiber bundles. The ceramic tile is highly brittle and is unable to reduce stress concentrations through local yielding but instead fractures when the local stresses become excessive.

A series of photoelastic tests were performed to show that the SIP does indeed transfer load to adjacent structure at discrete points causing stress concentrations which the intervening layer of RTV 560 adhesive is not stiff enough to redistribute. An indication of the severity of the stress concentrations expected is also obtained. This paper presents the results of the tests.

PHOTOELASTIC MODELS

To evaluate the tendency of the SIP to transfer load at discrete points, a series of experimental models configured as shown in Figure 4 were fabricated with photoelastically sensitive material, in place of ceramic tile, bonded using RTV 560 to the SIP. The SIP/photoelastic material system bonded on opposing surfaces to aluminum loading plates is tested in tension in a load frame located between the polarizer and analyzer of a white light transmission polariscope. As seen from the failure stress levels of Table 1, the load levels and resultant stress levels of interest are quite low and dictate the use of highly sensitive photoelastic model material. A commercially available sheet material, PSM-4*, with an elastic modulus of 6900 kPa (1000 psi) and a stress-fringe value of 17.5 kPa-cm/fringe (1 psi-in/fringe) was selected. Since the RTV 560 bonds at room temperature, residual bonding stresses were not noticeable at zero applied load conditions and compensation for residual stresses was not required.

Two model sizes were fabricated. One with 15.2 cm (6 inch) length shown in Figure 4 had six tapped holes in the base where threaded rods were installed to support dead weights distributed to provide either uniform tensile loads or

* Marketed by Photoelastic, Inc.

a combination of tension and moment loading to the SIP. The second model had a 7.6 cm (3 inch) length and had three tapped holes available to support the dead weight loads. Since the extensional modulus of the photoelastic material is well below that of the ceramic tile and the constraints at the tile are displacement constraints, the stress distribution across the photoelastic material is not necessarily the same as that which occurs in the actual tile; however, the local stress concentrations observed at the SIP/model interface should be representative of that which occurs in the actual tile/SIP interface. Two SIP thicknesses, 0.41 cm (.160 inch) and 0.23 cm (.090 inch) are currently used in the TPS and pads of both thicknesses were tested. Results were similar for both and only results from the 0.41 cm (.160 inch) thickness SIP are presented.

RESULTS

A typical light-field isochromatic fringe pattern is shown in Figure 5. The photoelastic model was 15.2 cm (6 inch) long and was bonded to 0.41 cm (0.160 inch) thick SIP. The model was loaded symmetrically, with weights suspended at two locations, under a total force of 45N (10 lb. force).

The fringe patterns near the SIP/PSM-4 interface and the PSM-4/aluminum interface are quite different. The fringe loops near the interface between the SIP and the PSM-4 clearly show that stress transfer occurs at discrete points. The number of fringe loops per unit length of interface gives an idea of the number of load transfer sites. While the number of fringe loops per interface length is not a constant, it indicates an average spacing of about 0.3 cm (1/8 inch) between adjacent fringe loops. This appears to be of the same order of magnitude as the average distance between two neighboring transverse load-carrying fiber bundles. A notable feature of the fringe loops, when viewed in white light, is that not all of them indicate an increasing fringe order; the fringe order decreases inside some of the fringe loops, indicating the lack of or reduced load transfer in some local regions. In the fringe loops for which the fringe order is increasing towards the center of the loop, the maximum fringe order measured varies from one loop to another.

The fringe pattern of Figure 5 shows a fringe order of about 1.5 over most of the length of the model, midway between the two interfaces which is equivalent to 41.4 kPa (6 psi). By comparison, the nominal applied stress is 46.2 kPa (6.7 psi). Some of the fringes at the SIP/PSM-4 interface are marked with their orders. Near the middle of the interface, a reduced fringe order of 0.5 occurs at two locations. A higher order of 2.5 is present at a few locations on the interface. By photoelastic compensation techniques, the maximum fringe order at any of the fringe loops was measured to be 3.25. This indicates a maximum interface stress, in the PSM-4, of 89.7 kPa (13 psi). Based on the average stress in the PSM-4 of 46.2 kPa (6.7 psi), this is equivalent to a maximum measured stress concentration factor of 1.94. However, based on an average stress in the SIP, which has a smaller cross-sectional area than the PSM-4, of 55.2 kPa (8 psi), the maximum measured stress concentration factor is 1.62. These values were typical for the different photoelastic models tested. It should be noted, however, that the model is 0.64 cm (1/4 inch) thick and the observed photoelastic response is an integrated effect through the thickness. The actual local stress concentration factor at a fiber bundle could be higher than that measured.

It is interesting to note that the fringe order at the ends of the interface between the PSM-4 and the aluminum is higher than in any other region, reaching 3.5. This stress concentration is not unexpected but is a function of the differential stiffness of the materials at the interface and would be different for ceramic tiles bonded to aluminum.

A Light-field isochromatic fringe pattern for the same photoelastic model subjected to combined moment and tension is shown in Figure 6. A load of 22.5N (5 lb. force) was applied at the right while there was no load at the left. While the photoelastic fringe pattern is unsymmetrical, due to the unsymmetrical loading, the general features of this pattern are similar to those described before.

The gradual development of the isochromatic fringes under increasing symmetrical and unsymmetrical loads is shown in Figures 7 and 8, respectively, for a 7.6 cm (3 inch) long model.

CONCLUSIONS

The ceramic tile thermal protection system of the space shuttle orbiter vehicle was modeled photoelastically to determine the nature of the load transfer between the strain isolation pad and the ceramic tile through the RTV 560 adhesive layer. The photoelastic results indicate that load transfer occurs at discrete locations and that the intervening RTV 560 adhesive layer cannot prevent stress concentrations from occurring in adjacent material. The photoelastic models showed that local stress concentrations at the tile/SIP interface can be expected to be at least 1.9 times the average stress in the tile.

REFERENCES

1. Williams, J. G., "Structural Tests on a Tile/Strain Isolation Pad Thermal Protection System," NASA Technical Memorandum 80226, March 1980.

2. Ransone, P. O. and Rummler, D. R., "Microstructural Characterization of the HRSI Thermal Protection System for Space Shuttle," NASA Technical Memorandum 81821, May 1980.

TABLE 1

AVERAGE ULTIMATE TENSILE STRENGTH OF TPS COMPONENTS AND FULL SYSTEM LOADED IN THE DIRECTION NORMAL TO THE BONDED SURFACES

	KPA	PSI
LI 900 CERAMIC RSI	165.5	24*
.160 INCH SIP	288.2	41.8
RTV 560 ADHESIVE	3309.	480
RTV/LI 900 RSI/RTV/.160 SIP/RTV	80.7	11.7
LI 2200 RSI	413.6	60
.090 INCH SIP	468.8	68
RTV 560 ADHESIVE	3309	480
RTV/LI 2200 RSI/RTV/.090 SIP/RTV	197.9	28.7

* VALUES OBTAINED FROM INTERNAL ROCKWELL INTERNATIONAL DOCUMENTATION.

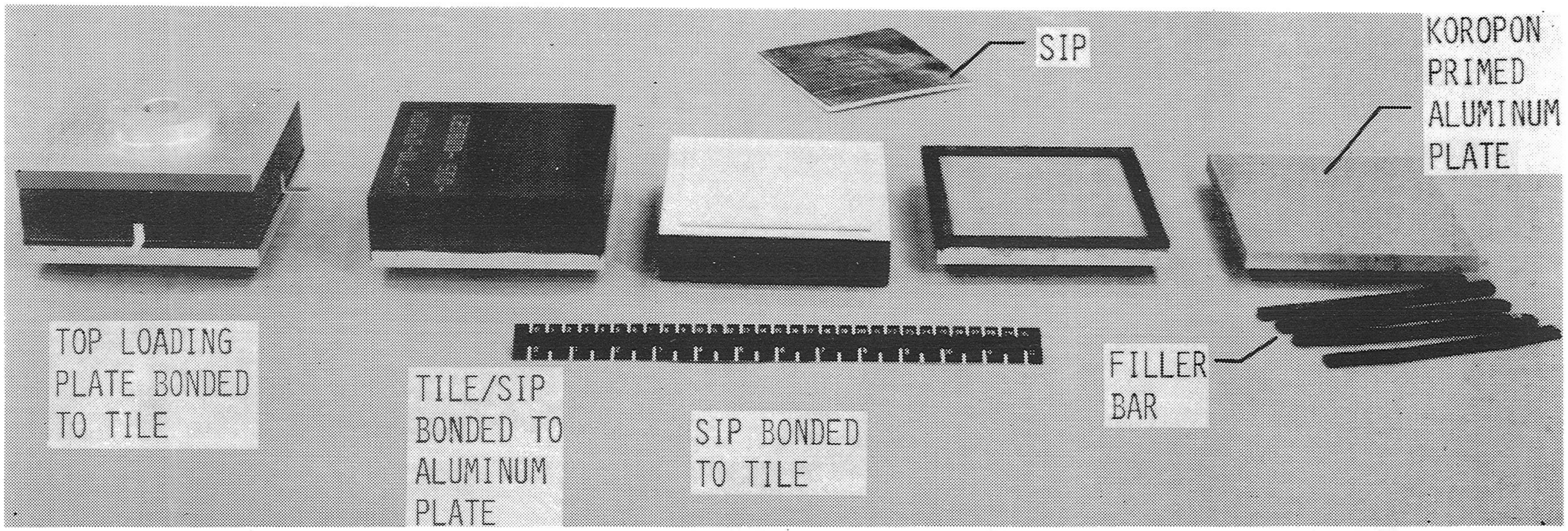


Figure 1. - Photographs illustrating sequential stages of specimen fabrication.

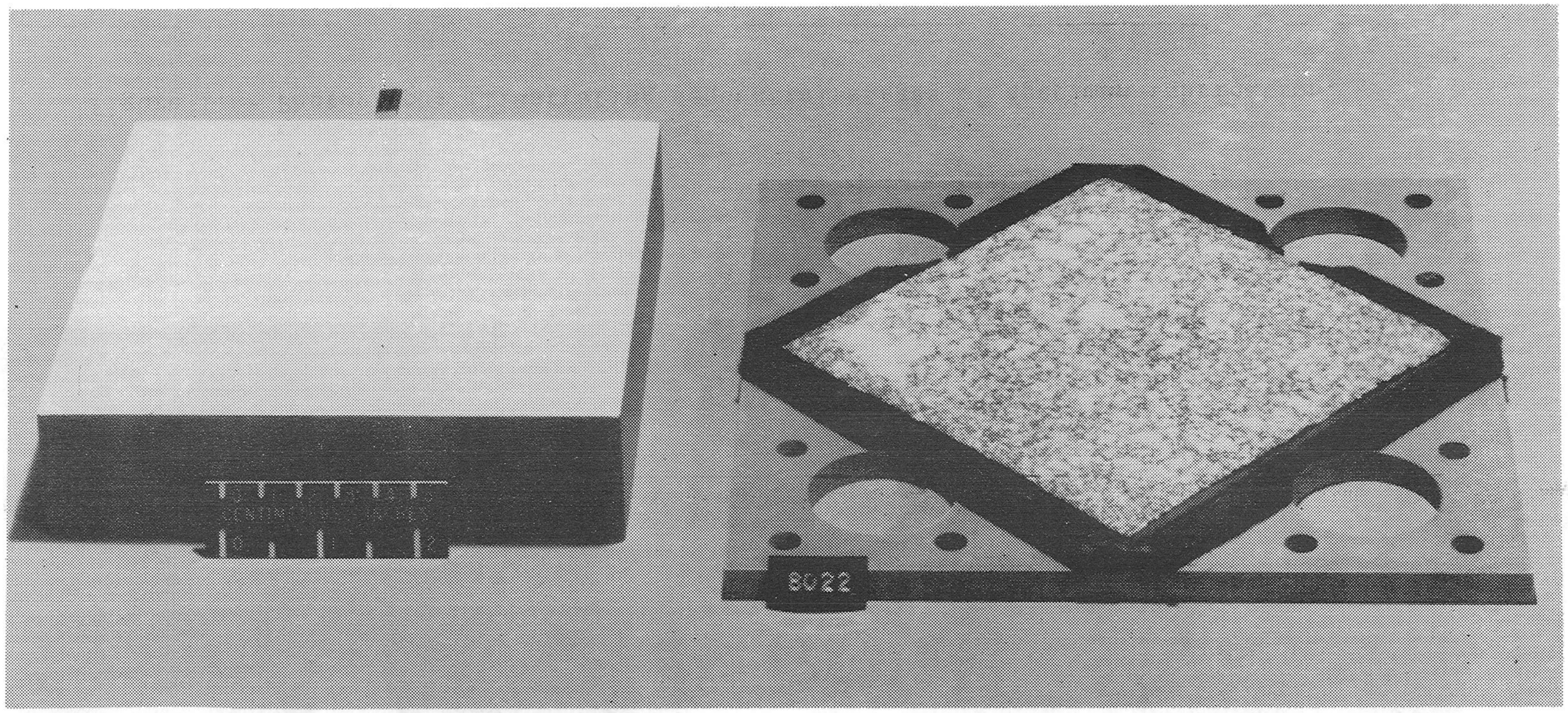
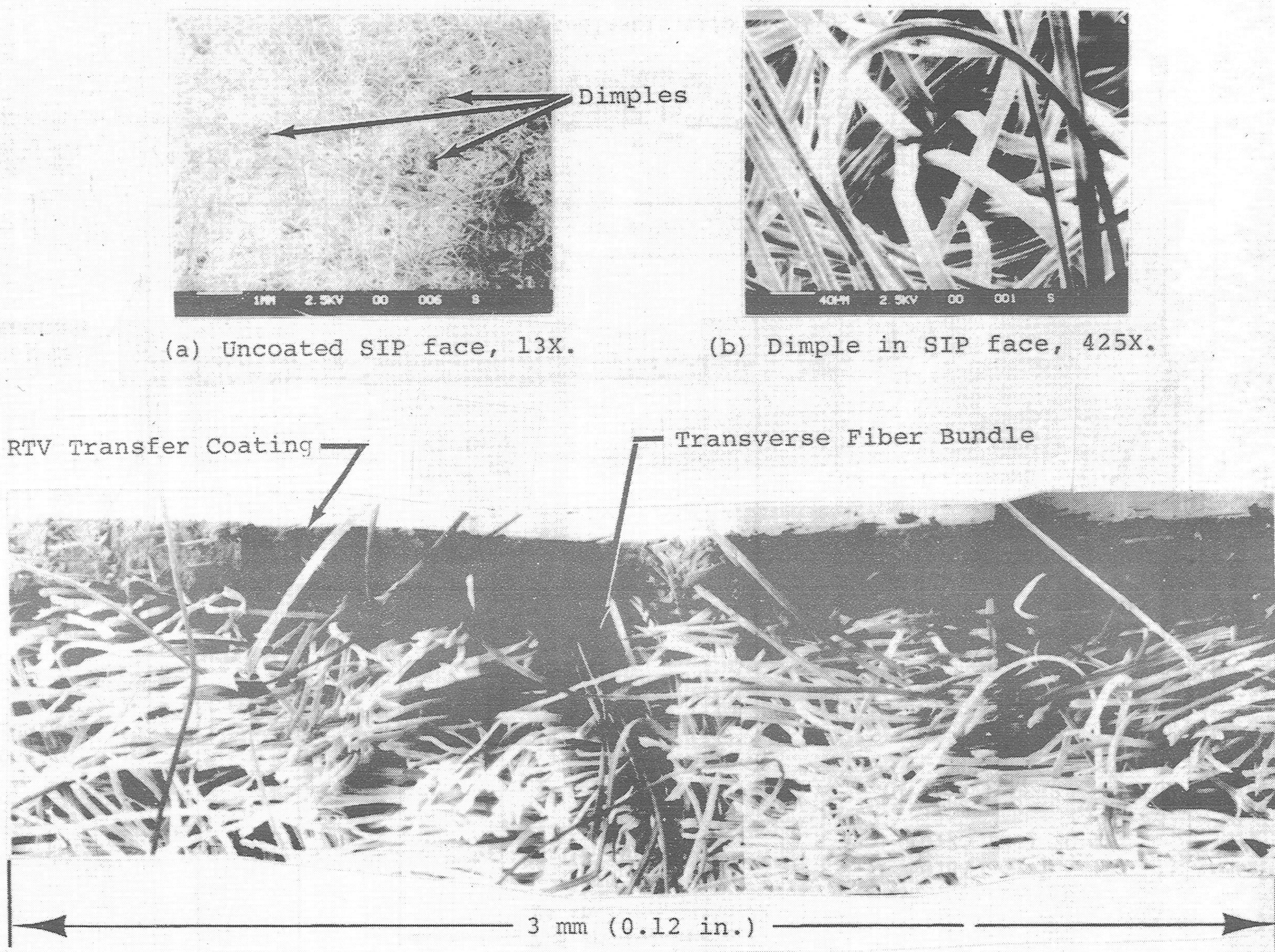


Figure 2 - Failure surface following transverse tension loading of specimen failing proof test acoustic criteria.



(a) Uncoated SIP face, 13X.

(b) Dimple in SIP face, 425X.

(c) Cross section of SIP showing fiber/transfer coat interface.

Figure 3 Photomicrographs of strain isolation pad (SIP).

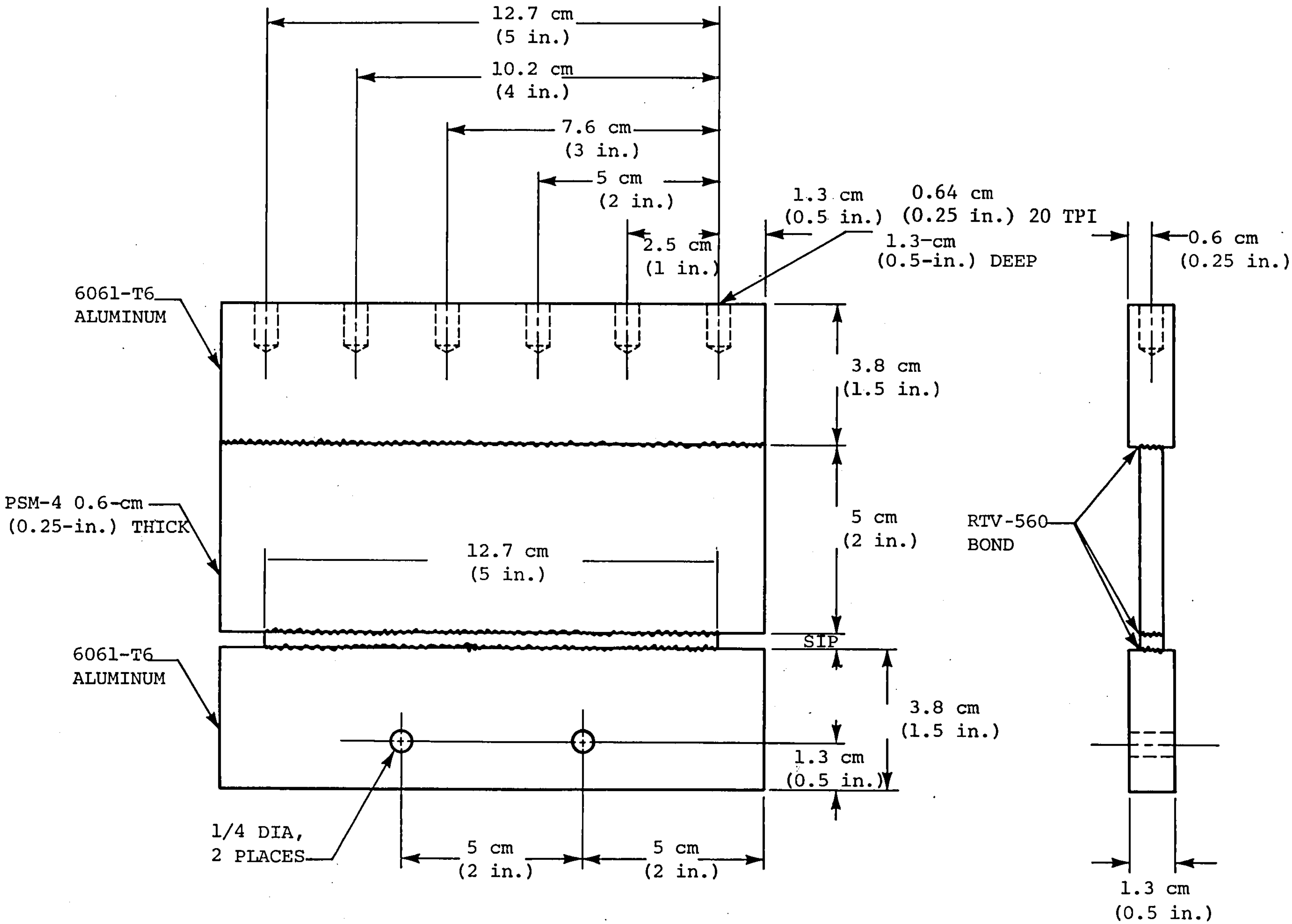


Figure 4 Photoelastic tile model.

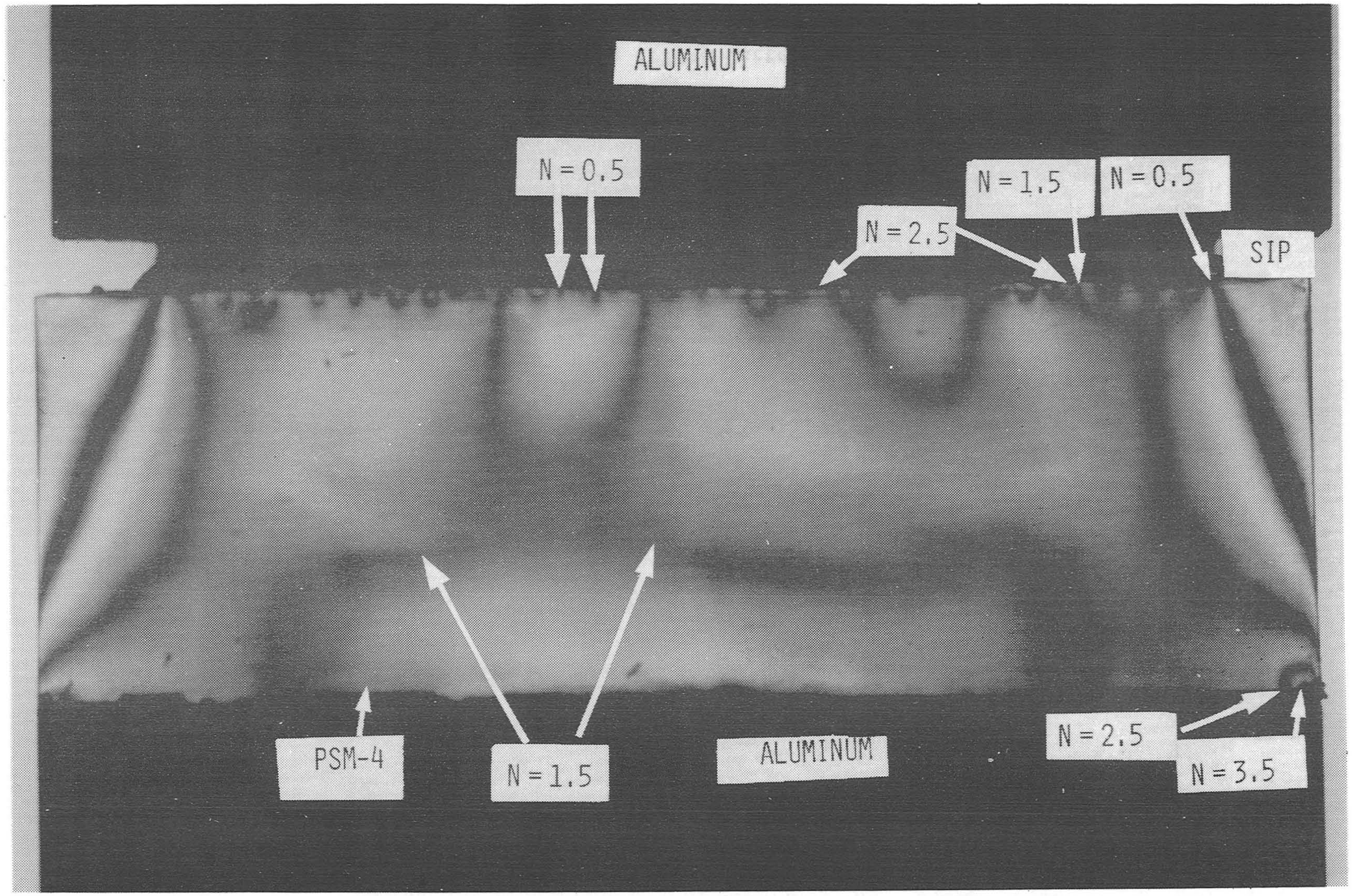


Figure 5 Light-field Isochromatic Fringe Pattern Under Tension.

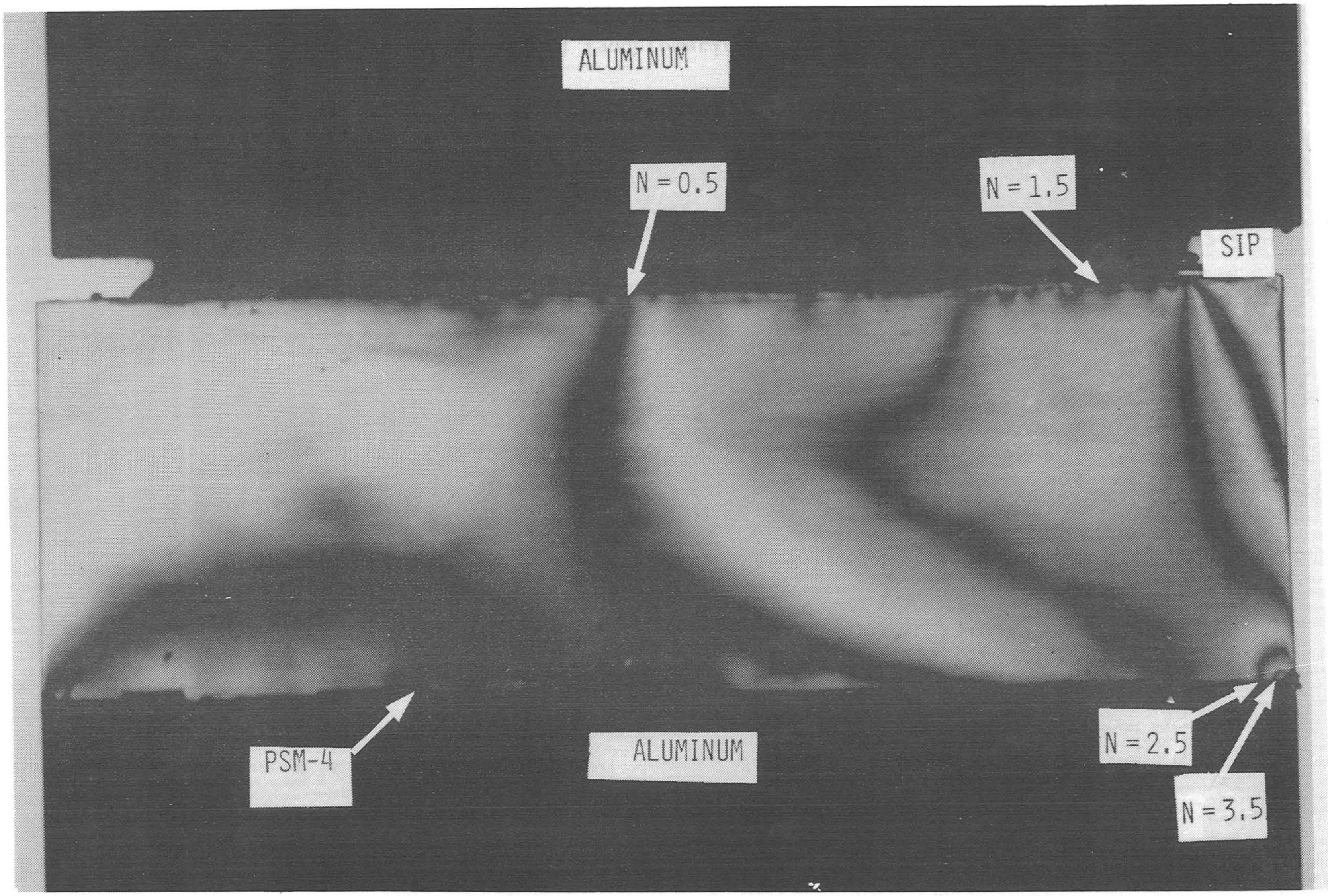


Figure 6 Light-field Isochromatic Fringe Pattern Under Combined Tension and Bending Moment.

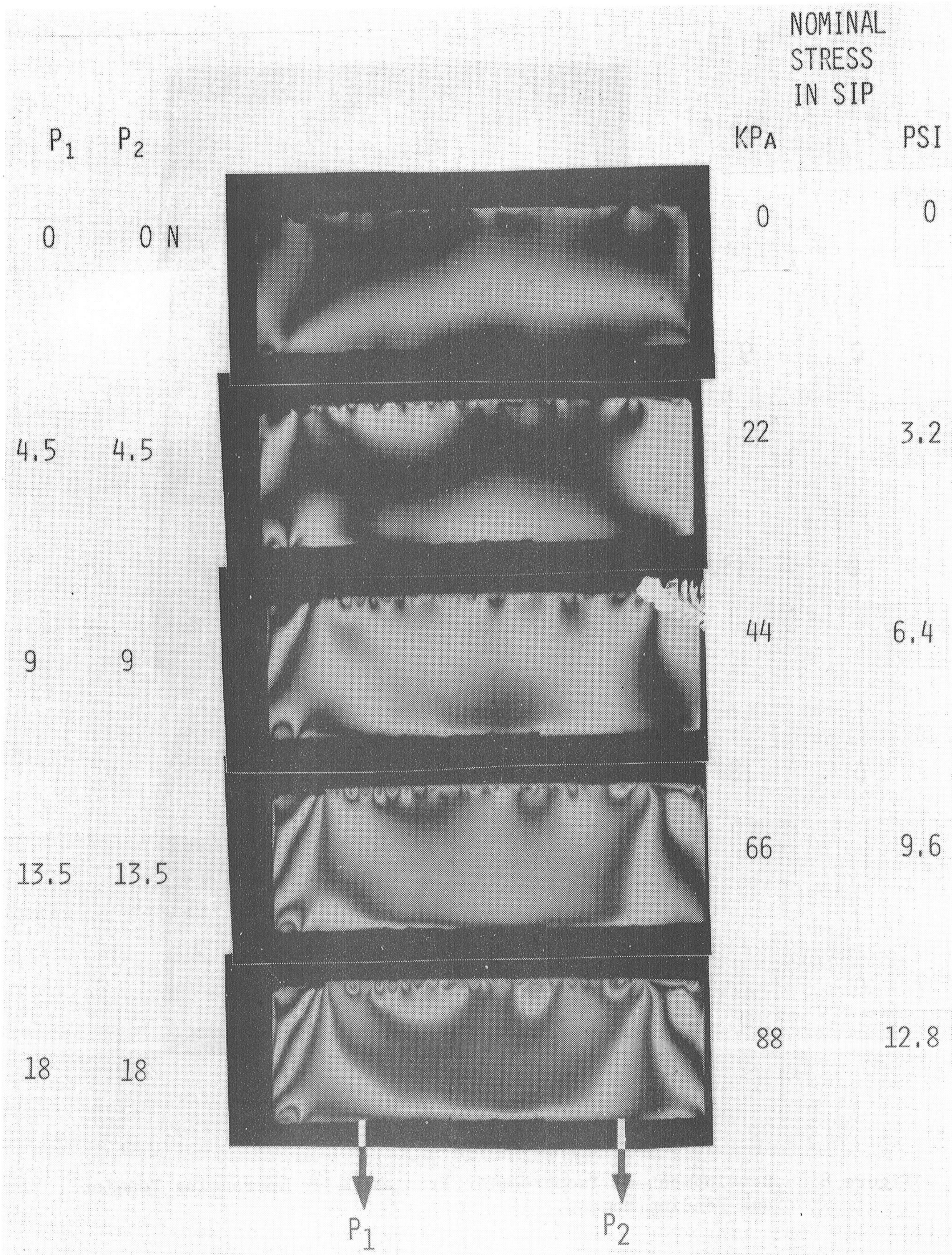


Figure 7 Development of Isochromatic Fringes Under Increasing Tension.

P_1	P_2
0	4.5 N
0	9
0	13.5
0	18
0	22.5

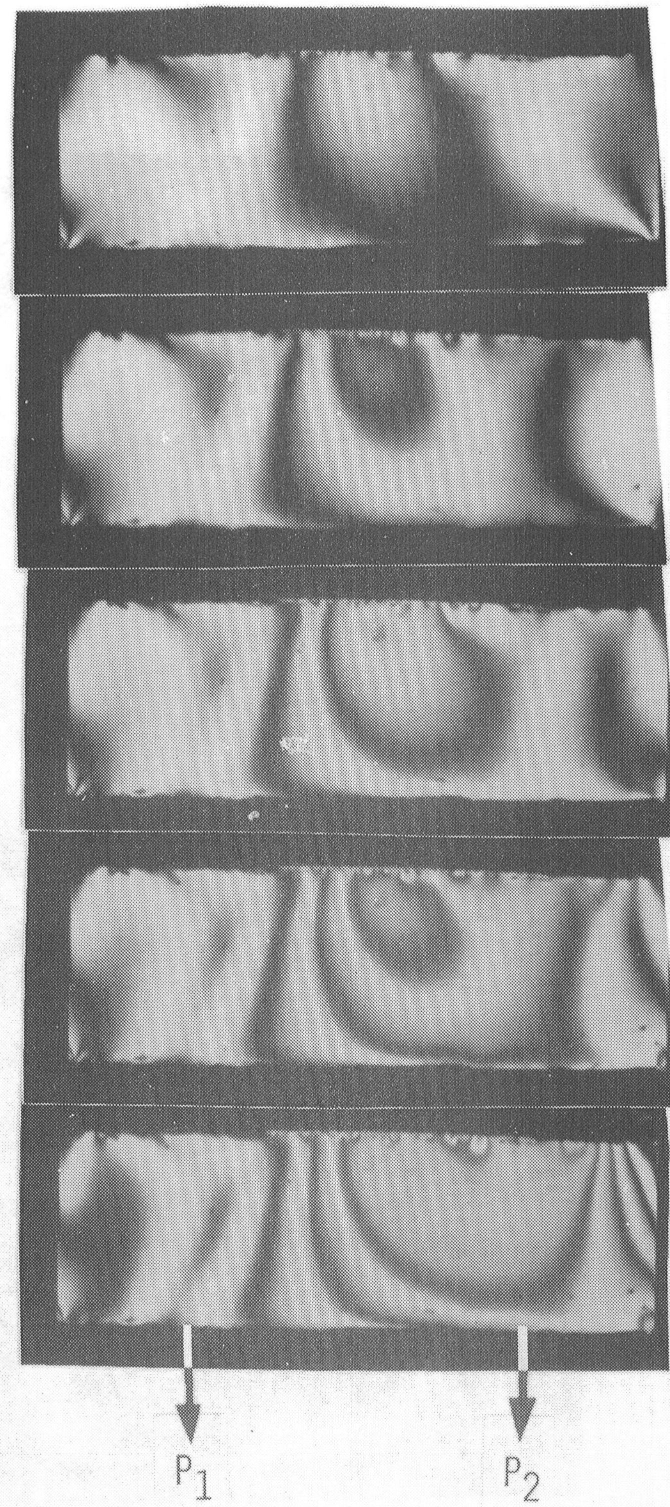


Figure 8 Development of Isochromatic Fringes Under Increasing Tension and Bending Moment.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-81866		

4. Title and Subtitle	5. Report Date
Photoelastic Tests on Models of Thermal Protection System for Space Shuttle Orbiter	August 1980
	6. Performing Organization Code
7. Author(s) *R. Prabhakaran and Paul A. Cooper	8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665	10. Work Unit No.
	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Supplementary Notes * Professor at Old Dominion University, Norfolk, Virginia.
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16. Abstract

The thermal protection system (TPS) of the space shuttle orbiter vehicle, consisting of ceramic tile/adhesive/strain isolation pad/adhesive/aluminum substructure, was modeled photoelastically. A highly sensitive photoelastic material was used in the models to show the nature of the stress-transfer between the strain isolation pad (SIP) and the ceramic tile through the RTV-adhesive layer. Isochromatic fringe patterns were obtained for models subjected to tension and combined tension and bending.

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Thermal protection system Shuttle TPS Strain isolation pad Reusable surface insulation	Unclassified - Unlimited Subject Category 39

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	16	A02

* For sale by the National Technical Information Service, Springfield, Virginia 22161