BONDING AREA OPTIMIZATION FOR REDUCING WAVEFRONT ERROR IN OPTICAL ELEMENTS

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ABSTRACT

The objective of this analysis is to recommend an optimal bonding configuration for a large Dove prism for minimal wavefront error, maintaining bond strength while subjected to severe environmental conditions.

1. INTRODUCTION

The mechanical design of optical systems is characterized by the minimization of the influence of the mechanical structure and environment on the optical elements and their performance.

Differences in coefficients of thermal expansion between the elements such as structure, adhesives and optical elements can distort optical elements such as mirrors and prisms reducing image quality, while being subjected to temperature differences.

Dove prism reverses the image when it is held as shown in Fig. 1. The image is inverted when the prism is turned about the axis through an angle of 90°. Its large face (the c dimension in Fig. 1) acts as a mirror, therefore only three faces can be used for bonding. The prism can be used only in parallel light.

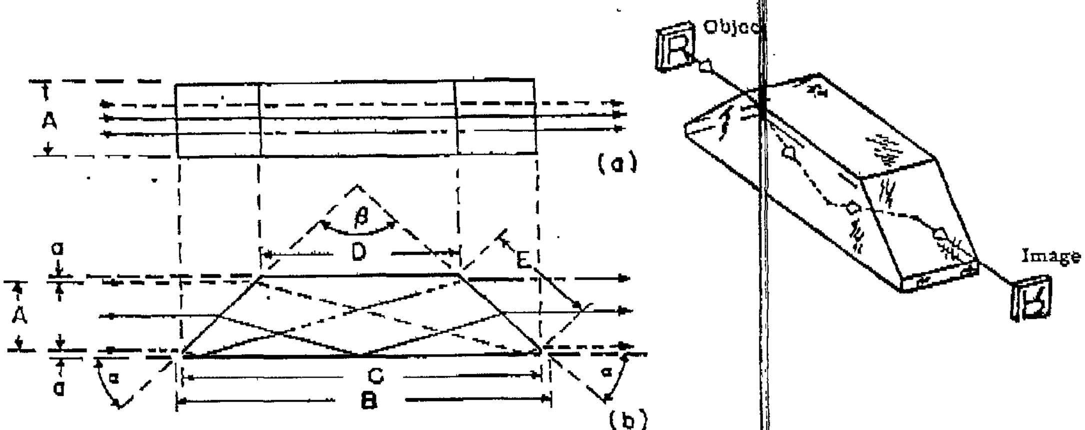

Fig. 1: Dove Prism

Measurements before and after Dove prism bonding using Uralane adhesive showed a wavefront error of 0.2 λ (0.1266 μm), due to the bonding process itself.

This value is two times the maximum allowed and is caused by adhesive shrinkage during the curing process, which distorts the prism mirror face.

Wavefront error affects the image sharpness and resolution. This analysis examines four different bonding configurations, the resulting wavefront error and the stresses on the Uralane adhesive and prism results from the environmental conditions.

The optimal configuration was impelemented successfully in the bonding processs by reducing wavefront error by 60% without a substantial decrease in the bonding strength.

2. MODEL DESCRIPTION

Four detailed F.E. models were built including the Dove prism, Uralane adhesive and prism housing.

Each model contained different bonding configurations.

Model 1 represents the initial (bad) configuration in which the whole side areas and the small face were used for bonding.

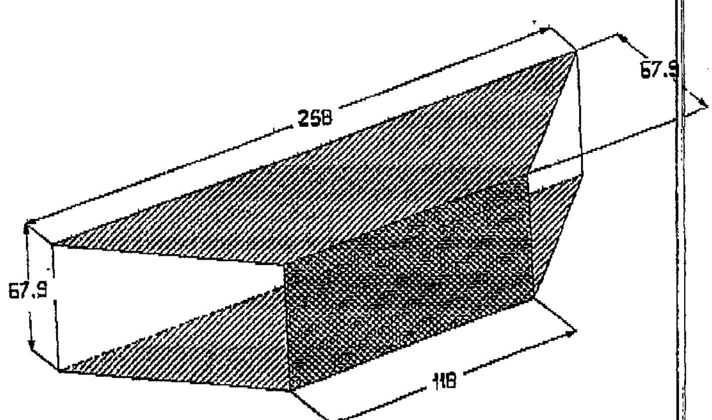

Fig. 2: The First Bonding Configuration

Figs. 3 – 5 show the F.E. model of the first configuration.

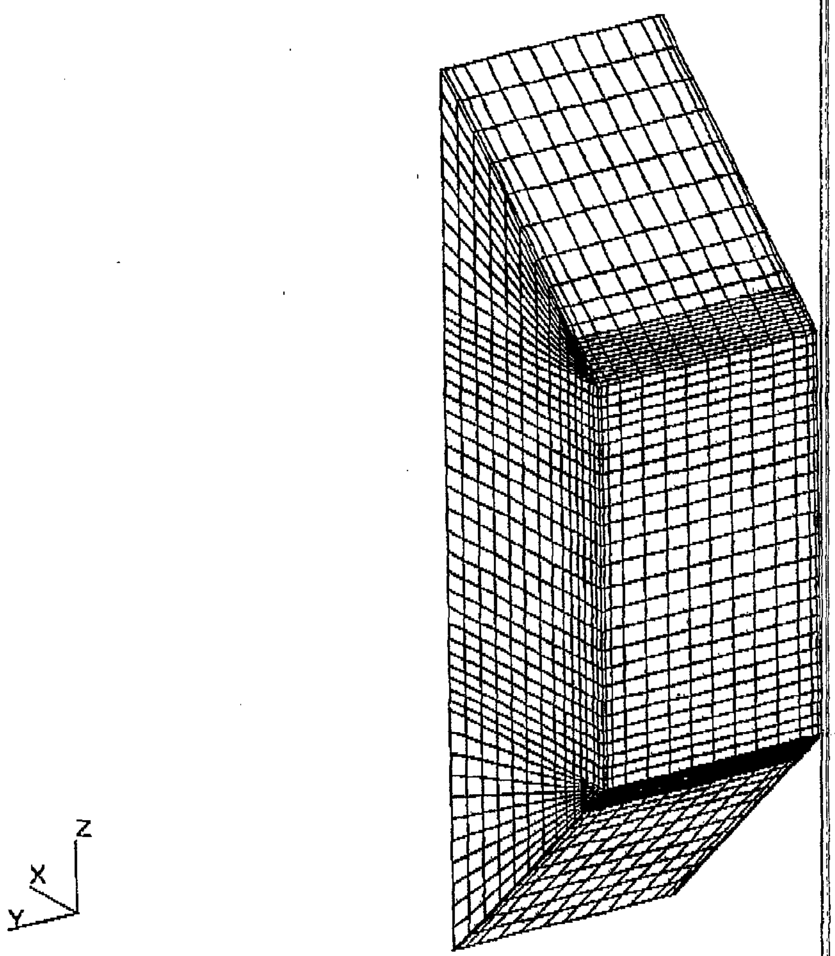

Fig. 3: Dove Prism F.E. Model

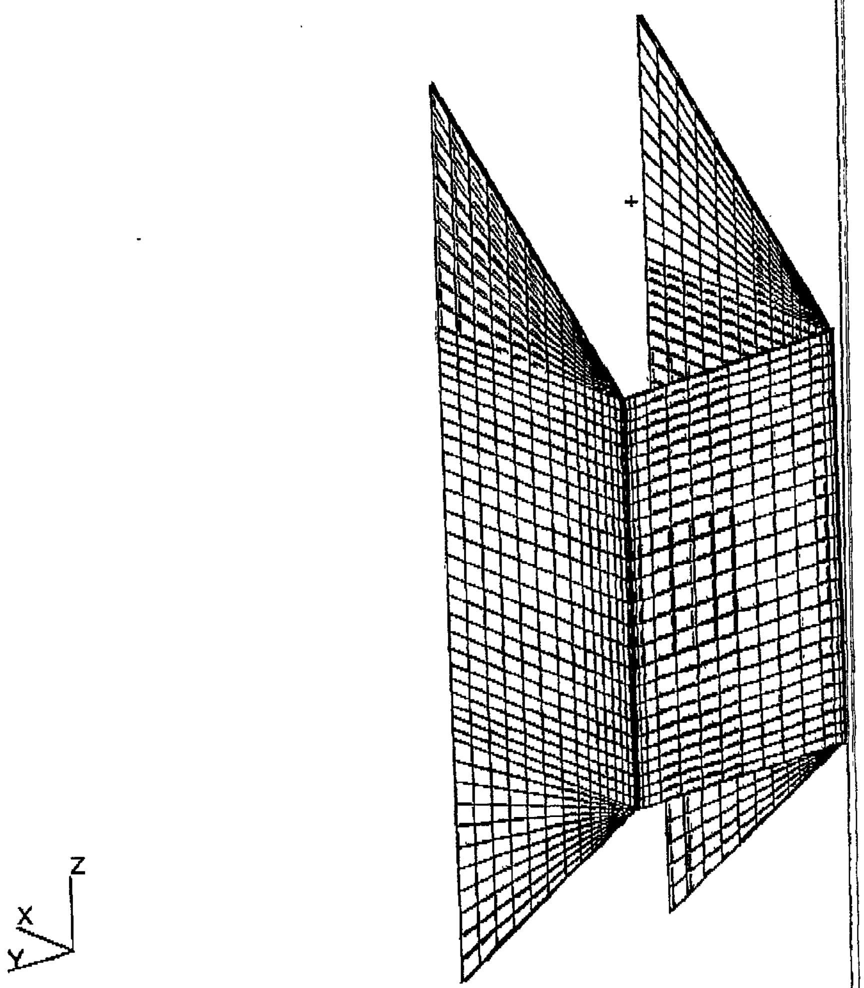

Fig. 4: Uralane Adhesive F.E. Model

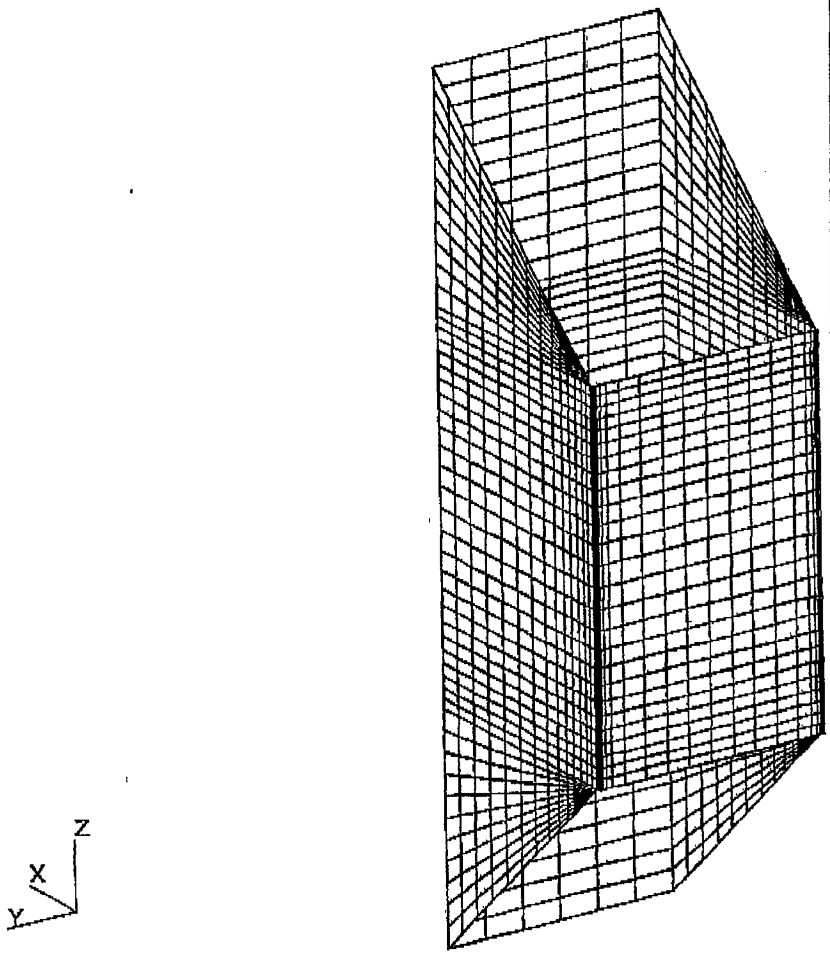

Fig. 5: Dove Housing F.E. Model.

The second model describes bonding without the four side triangle areas.

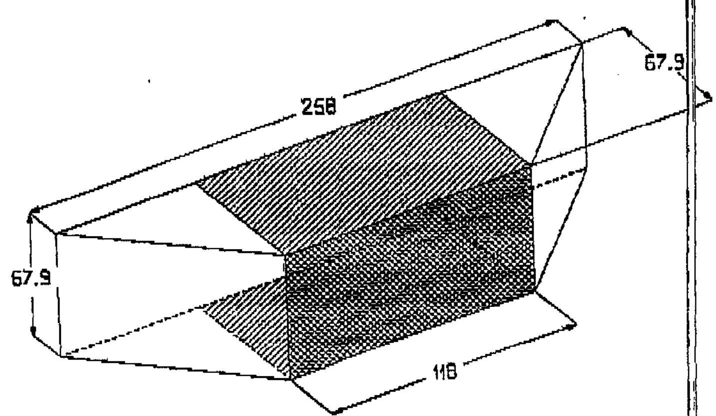

Fig. 6: The Second Bonding Configuration

The third model describes bonding without the four side triangle areas and a 20 mm wide area on the prism sides.

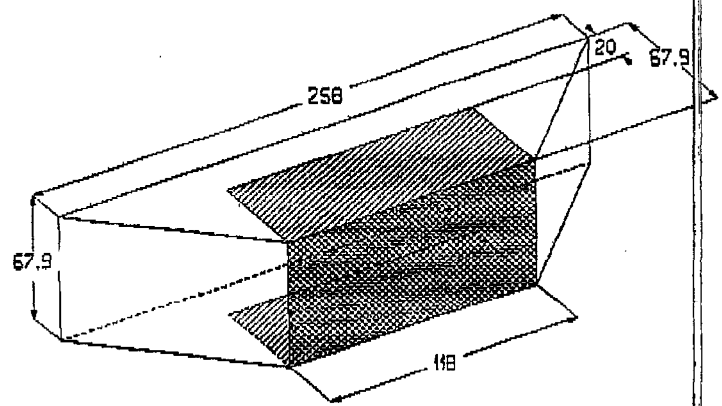

Fig. 7: The Third Bonding Configuration

The fourth model describes bonding without the 20 mm wide area on the prism sides.

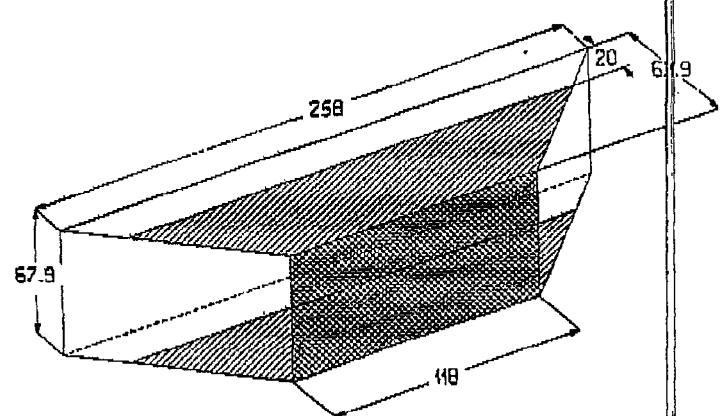

Fig. 8: The Fourth Bonding Configuration

3. MATERIALS

The adhesive is Uralane with the following properties:

At -30°C:

$E = 0.65$ kg/mm². $G = 0.22$ kg/mm², $\nu = 0.47$, $\rho = 1\times10^{-6}$ kg/mm³, $\alpha = 215 \times 10^{-6}$ mm/mm°C, $\tau_{cr} = 0.45$ kg/mm²

At 23 °C:

$E = 0.32$ kg/mm². $G = 0.13$ kg/mm², $\nu = 0.20$, $\rho = 1\times10^{-6}$ kg/mm³, $\alpha = 210 \times 10^{-6}$ mm/mm°C, $\tau_{cr} = 0.16$ kg/mm²

At 75°C:

$E = 0.17$ kg/mm². $G = 0.08$ kg/mm², $\nu = 0.11$, $\rho = 1\times10^{-6}$ kg/mm³, $\alpha = 202 \times 10^{-6}$ mm/mm°C, $\tau_{cr} = 0.08$ kg/mm²

The Dove prism is made of F2 glass with the following properties:

$E = 5910$ kg/mm². $G = 2412$ kg/mm², $\nu = 0.225$, $\rho = 3.61\times10^{-6}$ kg/mm³, $\alpha = 8.2 \times 10^{-6}$ mm/mm°C, $\tau_y = 1$ kg/mm²

The Dove prism housing is made of 17- 4 PH H1150 Steel with the following properties:

$E = 20035$ kg/mm². $G = 7876$ kg/mm², $\nu = 0.27$, $\rho = 7.82\times10^{-6}$ kg/mm³, $\alpha = 11.9 \times 10^{-6}$ mm/mm°C, $\tau_y = 91.5$ kg/mm²

4. LOADS

The principal assumption is that adhesive volume shrinkage is 0.6% after the curing process, which is 0.2% in the longitudinal direction.

This shrinkage is equivalent to cooling the system from 34.9°C to room temperature (25°C).

$$T_{REF} = 25 + \frac{0.002}{210 \times 10^{-6}} = 34.9^{\circ}C$$

In order to simulate the curing effect on the Uralane, the reference temperature of the adhesive was set to 34.9°C while the reference temperature of the other parts of the model (prism and housing) was set to 25°C.

The displacements of the mirror face of the prism were found using MSC/NASTRAN and posted using MSC/PATRAN. The mirror face displacements were processed using a Fortran program in order to find the wavefront error.

Gravity loads of 120 g on the front and side directions, at extreme temperatures of -30°C and +71°C were run and the resulting stresses on the prism and adhesives were found.

5. BOUNDARY CONDITIONS

During the "curing" runs, the Dove housing was mathematically held.

At the gravity load runs, hinge conditions were given to the prism housing.

6. RESULTS

The following table summarizes the wavefront errors at the four bonding configurations:

Table 1: Wavefront Error at the Four Bonding Configurations

Model Number	Wavefront Error
1	0.27 λ
2	0.16 λ
3	0.11 λ
4	0.32 λ

Figs. 9 and 10 show the resulting displacements on the prism mirror face while subjected to curing loads at the 1st and 3rd configurations.

Figs. 11 and 12 show the stresses on the adhesive and prism while subjected to 120 g side load at -30°C ambient temperature on the best configuration (Model 3).

Figs 13 and 14 show wavefront error measurements of the prism, before and after bonding, according to the 3rd configuration.

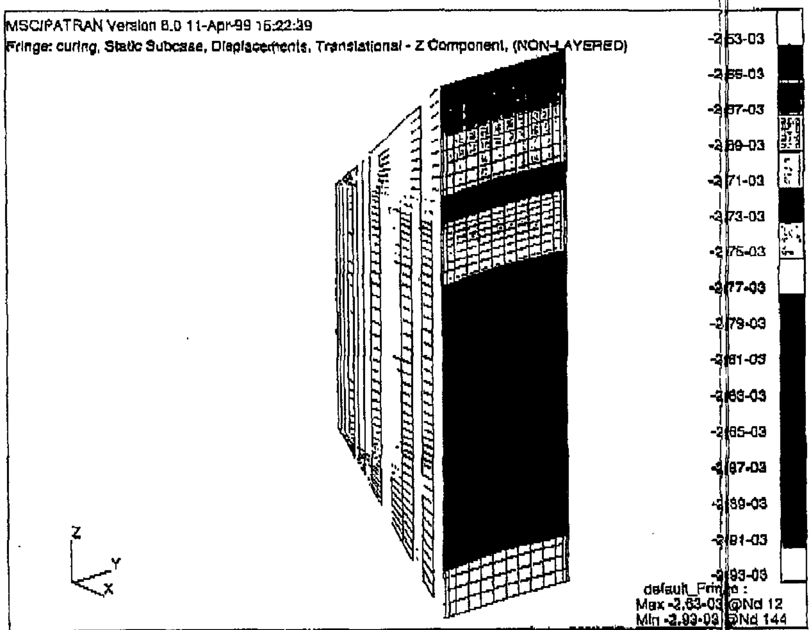

Fig. 9: The Displacement on the Mirror Face Perpendicular Direction while Subjected to Curing Loads in the 1st Configuration.

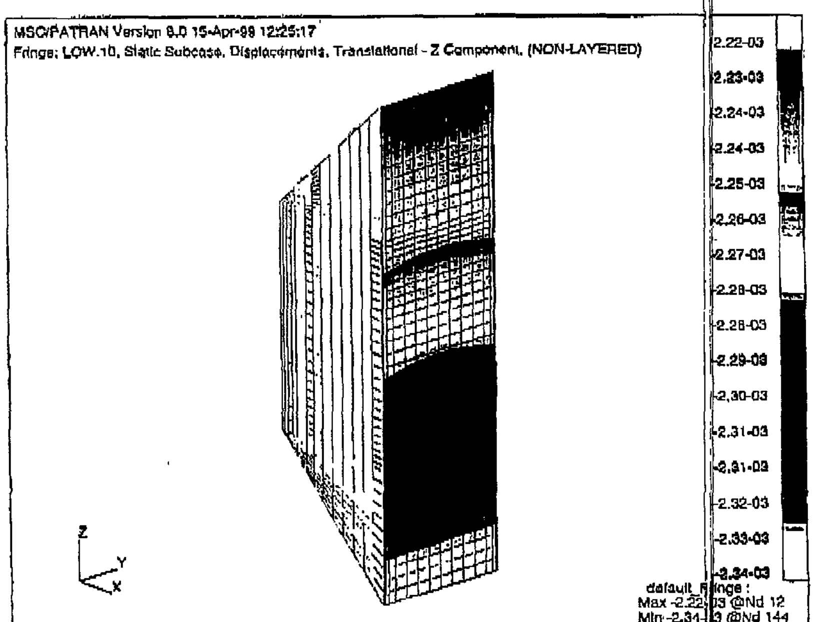

Fig. 10: The Displacements on the Mirror Face Perpendicular Direciton while Subjected to Curing Loads in the 3rd Configuration.

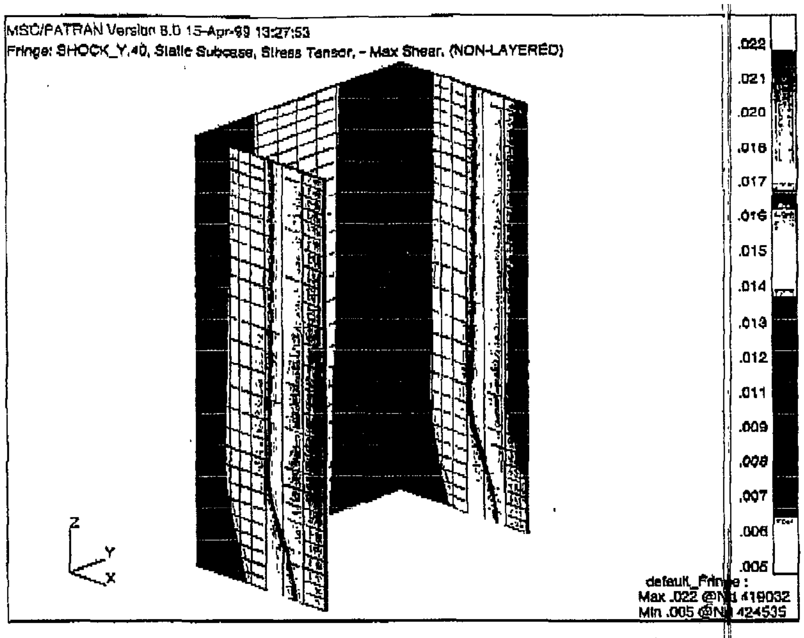

Fig. 11: The Shear Stresses on the Uralane while Subjected to 120 g side load at -30°C Ambient Temperature – 3rd Configuration ($\tau_{max} = 0.02$ kg/mm^2)

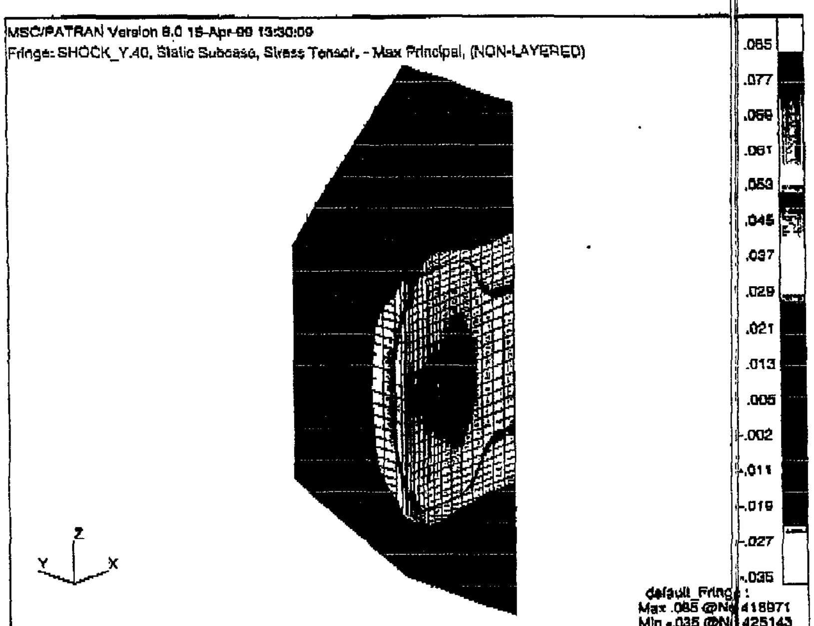

Fig. 12: The Tensile Stresses on the Prism while Subjected to 120 g side load at -30°C Ambient Temperature – 3rd Configuration ($\sigma_{max} = 0.085$ kg/mm^2).

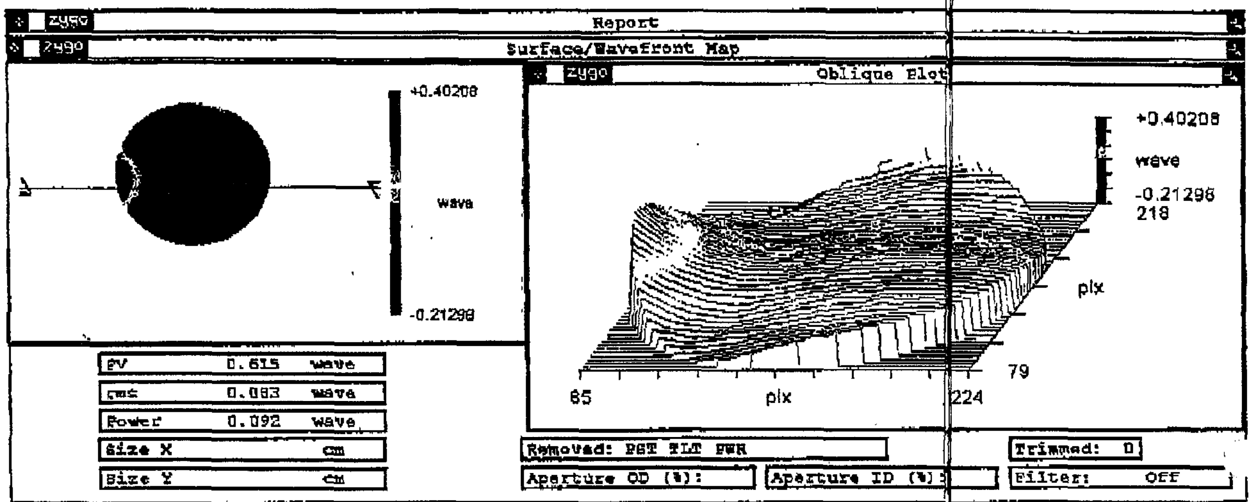

Fig. 13: Wavefront Error Measurement of the Prism Before the Bonding (0.083 λ rms)

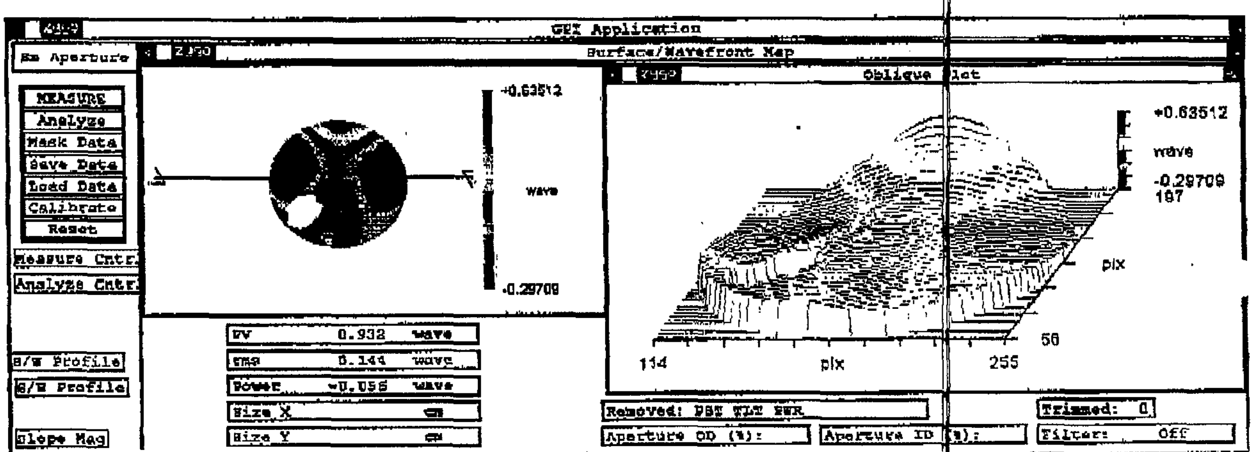

Fig. 14: Wavefront Error Measurement of the Prism After Bonding According to the 3rd Configuration (0.144 λ rms)

7. CONCLUSIONS

1. The wavefront error accepted from the analysis fits the average measured during the bonding process.
2. The optimal bonding configuration is the 3rd. It decreases wavefront error by 60% without significant reduction of the bonding strength..
3. The optimal configuration was implemented in the bonding process and showed similar improvement.

REFERENCES

1. Schott, Optical Glass Catalog.
2. Furane Products Company Information Papers, 5121 San Fernando Rd., West Los Angeles, CA 90039.
3. OISD Encyclopedia