CONF-960706--1

AN EXPERIMENTAL INVESTIGATION OF THE INTERACTION OF PRIMARY AND SECONDARY STRESSES IN FUEL PLATES

W.F. Swinson, R.L. Battiste, G.T. Yahr
Engineering Technology Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-8051

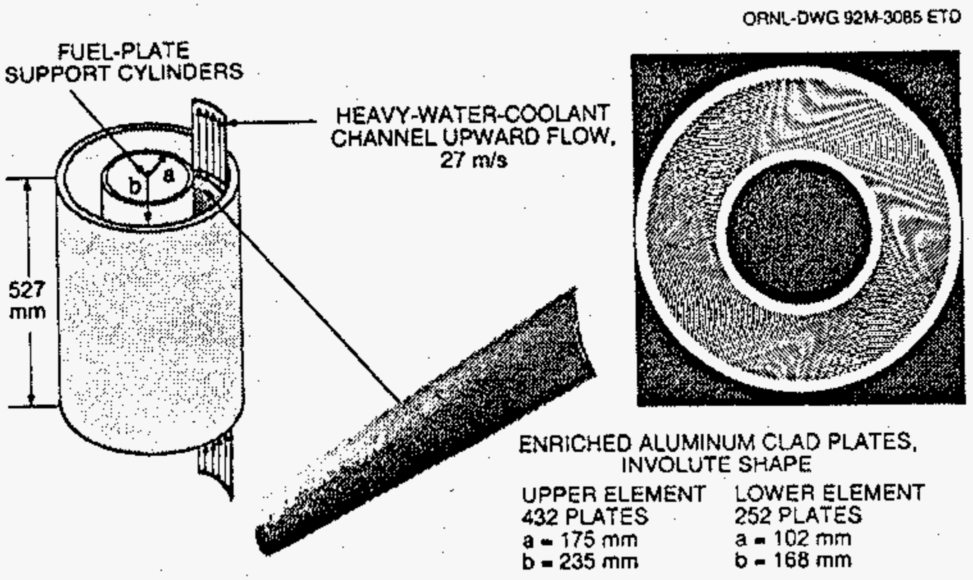
ABSTRACT

If the load is not relieved as a structure starts to yield, the induced stress is defined as primary stress. If the load relaxes, as a structure begins yield the induced stress is defined as secondary stress. In design it is not uncommon to give more weight to primary stresses than to secondary stresses. However, knowing when this is good design practice and when it is not good design practice represents a problem. In particular, the fuel plates in operating reactors contain both primary stresses and secondary stresses and to properly assess a design there is a need to assign design weights to the stresses. Tests were conducted on reactor fuel plates intended for the Advanced Neutron Source (ANS) to determine the potential of giving different design weights to the primary and secondary stresses. The results of these tests and the conclusion that the stresses should be weighted the same are given in this paper.

INTRODUCTION

In the design of the fuel plates for the ANS reactor [1], enriched fuel was to be clad in aluminum and formed into a thin (1.27 mm) involute shaped plate, Fig.1. The plates were to be held apart at the specified spacing of 1.27 mm by an inner support cylinder and an outer support cylinder, also illustrated in Fig. 1. The use of involute plates makes it possible to maintain a constant spacing at all locations between adjacent plates. The uniform spacings between adjacent plates serve as cooling channels, where heavy water is forced through the channels for controlling the plate temperatures. Reactions taking place in the plates during reactor operation cause the plate temperatures to be at higher temperatures than the support cylinders and are the cause of thermal stresses in the plates. In addition, the turbulent coolant flow takes on different flow patterns in adjacent channels and produces different pressure distributions on each side of each plate. These different pressure distributions cause pressure loads on each plate and induce additional stresses in the plates. Because the stresses from the thermal loads and from the pressure (flow) loads may produce different effects in the plates, assessing the total stress for design purposes as the sum of the stresses from each load is not necessarily correct nor is it necessarily good design practice.

If a plate is loaded by pressure and starts to yield, it has the propensity with a steady load to continue deformation until



ORNL-DWG 92M-3085 ETD

Fig.1. Reactor Fuel Plate Arrangement

failure. Stresses caused by such continuous or sustained loadings as these pressure loads are sometimes designated "primary stresses", [2]. If a plate is thermally loaded and the structural material starts to yield, slight deformation may limit or reduce the magnitude of the thermal load. The limit or reduction in the thermal load depends on the total stress state and deformation in the structural material. Stresses induced by these thermal loads also may be limited or relax depending on the deformation and the total stress state of the material involved, and, therefore, are sometimes designated "secondary stresses", [2]. Because of the possibility of producing different effects on structures, it is not uncommon design practice to assign different "weights" to the primary stresses and to the secondary stresses, [2]. Tests were conducted on the proposed ANS reactor plates to assess the potential of assigning different weights to the primary and to the secondary stresses.

EXPERIMENTAL ARRANGEMENT

Aluminum plates without the enriched fuel were fabricated by taking 6061-O aluminum plates, 1.27 mm thick, and pressing between two stainless steel mandrels that had been machined to the specified involute dimensions. Each plate while pressed between the mandrels was heated to 385°C, held for two hours at this temperature and then slowly allowed to cool to room temperature for removing residual stresses that developed during the forming of the plates. The test plates on removal from the mandrels conformed without any detectable variation to the mandrel pattern. Two plates were used to form the test section and are illustrated in Fig. 2.

Secondary stresses were induced in the plates by maintaining a thermal gradient between the plates and the support boundaries. To achieve the thermal gradient, the test section was placed in an oven and, while the oven temperature was increased, the support boundaries were cooled by flowing water through them. The support boundaries were covered with insulation to help make maintaining a thermal gradient more efficient. The ANS fuel elements were designed so that one of the support boundaries illustrated in Fig.1 could float or rotate as a way of reducing the thermal stresses. To simulate this boundary condition, the inside support boundary needed freedom to rotate but the radial displacement needed to be restrained. Therefore, the inside boundary of the test section was designed cylindrical in shape and forced to move in a slot that would allow rotation but constrain radial displacement, Fig.2.

Inducing primary stresses in the plates was based on some earlier tests and work with fuel plates [3] which indicated that, for design purposes, the load on the plates from the coolant flow could be simulated by applying pressure on one side of a given plate. Therefore, the space between the test plates was sealed at each end with a flexible silicone rubber so that pressure could be introduced into the space. Three small tubes, 0.70 mm inside diameter and 1.08 mm outside diameter, were routed through the silicone rubber seal and used to transmit pressure into the space

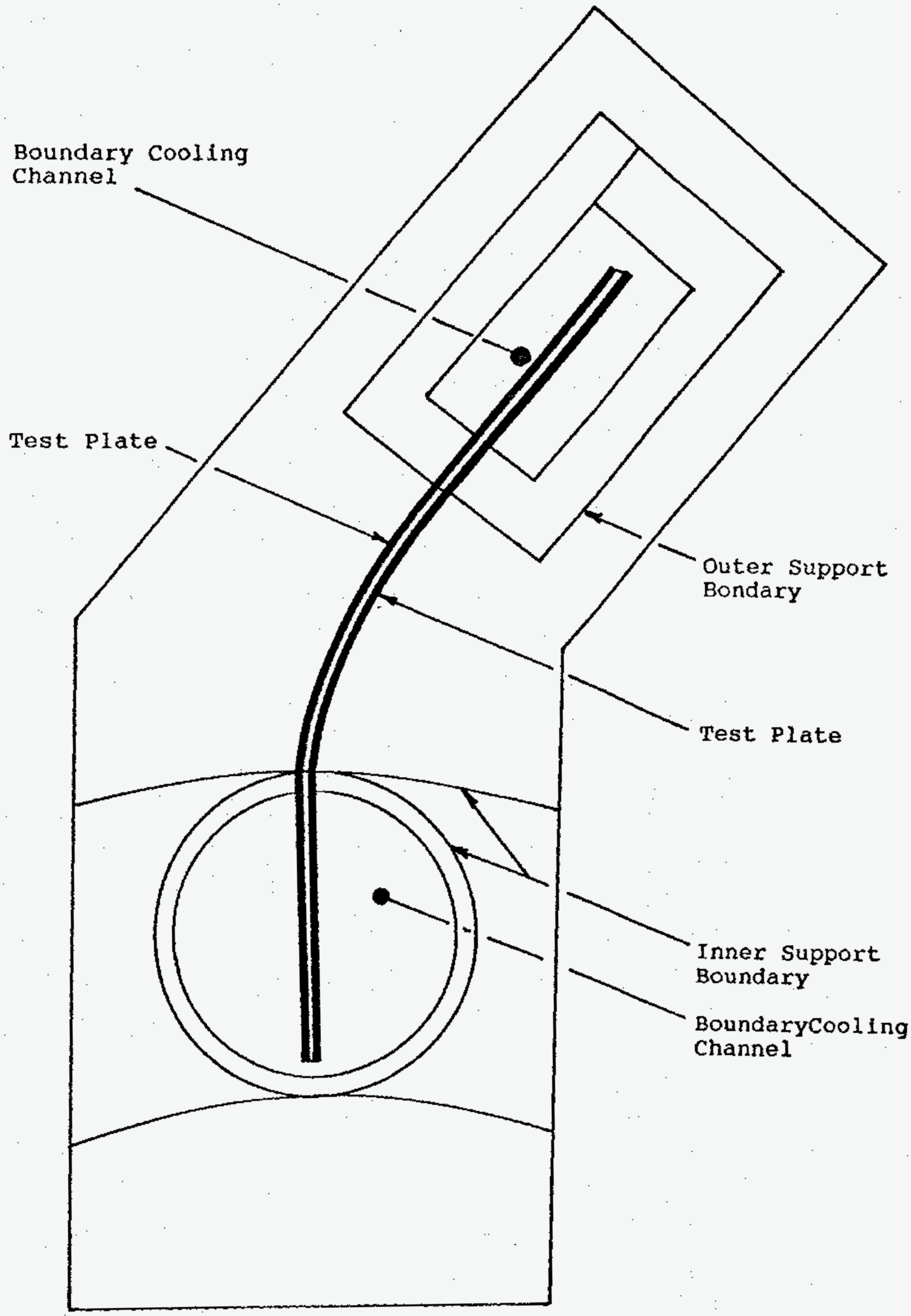


Fig.2. Cross Section of the Test Section

when required. Different pressures in the test space corresponded to different flow velocity loads in the reactor and was the source of the primary stresses in the test plates.

The test section before the support boundary insulation was attached is shown in Fig.3. In this picture some of the test sensors can be seen. Twelve strain gages (three pairs on each plate) were mounted on the plates to monitor the plate strains in the span direction and in the longitudinal direction that developed at these locations during each test. Data from the strain gages were used to calculate the stresses at the test points on each plate. The test points were located on the plates at the inner boundary, at the outer boundary and at the location which had the largest deflection from the pressure load. For convenience, the gages were mounted only on the plate surfaces which were exterior; thus, on one test plate the gages were on the convex surface and on the other test plate the gages were on the concave surface. The location and identification number of the gages are shown in Fig.4. Data from each test included: the oven temperature, the temperature of the coolant entering and leaving the inner boundary, the temperature of the coolant entering and leaving the outer boundary, the temperature of each plate, the pressure load, time, and strain values. The strain values were temperature compensated by using the plate temperature and the manufacturer's strain-temperature function for that gage. The test section ready for testing is shown in Fig.5.

TEST RESULTS

Each test consisted of taking three sets of data, first, data with a pressure load only, second, data with the thermal load only, and, third, data with the thermal and pressure load combined. The same thermal load was used in each test while the pressure load was increased for each test. The thermal load as noted previously was achieved by having the test section in the oven and raising the oven temperature. An oven temperature of 260°C was selected as the test temperature and corresponded to the limit suggested by the manufacturers of some of the components used in the test section. Typically, the boundary cooling water was adjusted for an inlet temperature of 26.8°C and an outlet temperature of 30.9°C. This temperature combination, which was found by trial and error, yielded the maximum temperature gradient between the plates and support boundaries. The temperatures of the plates were taken with temperature sensors attached to the plates. In all there were six tests run with eighteen data sets generated. During the last test with the combined pressure and thermal load, failure of both plates, as evidenced by a large bulge in each plate, occurred. Calculations for each test point were made from the temperature corrected strain readings for each data set to give the principal stresses in the span direction and in the longitudinal direction. These calculated principal stresses correspond to the primary stresses, to the secondary stresses, or to the combined stresses depending on the load being pressure only, temperature only, or combined pressure and temperature.

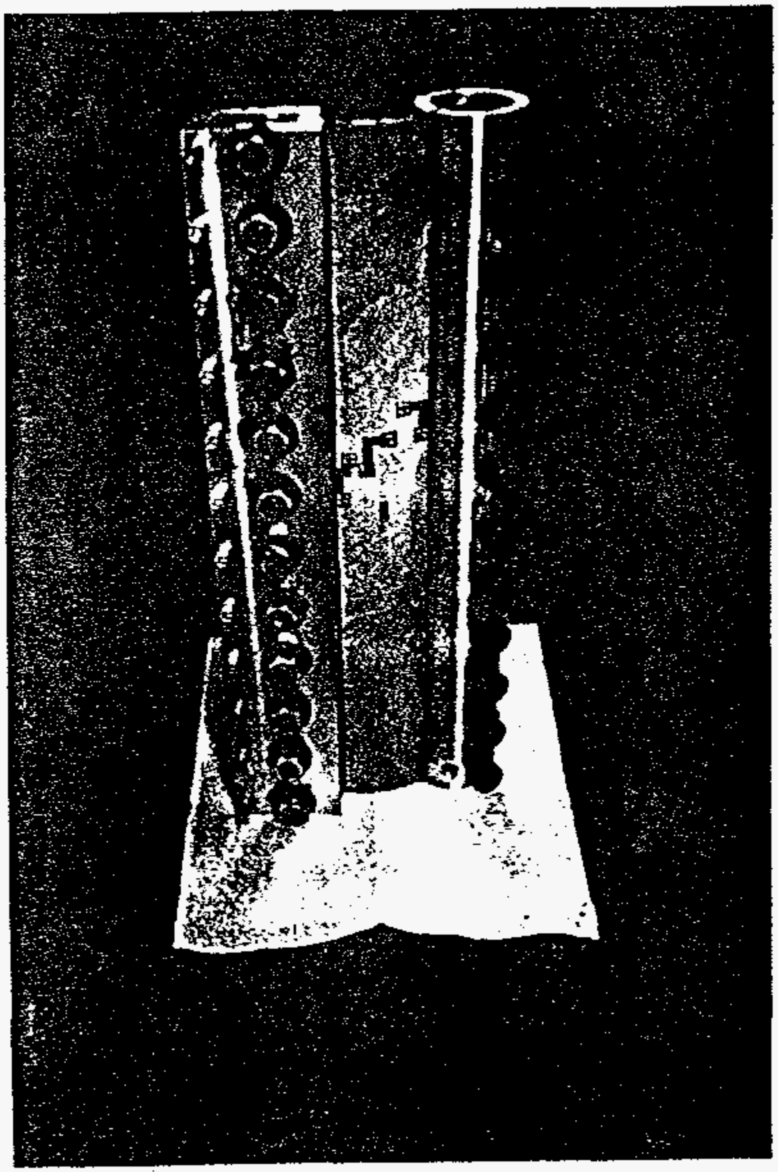


Fig.3. Test Element Before Assembly

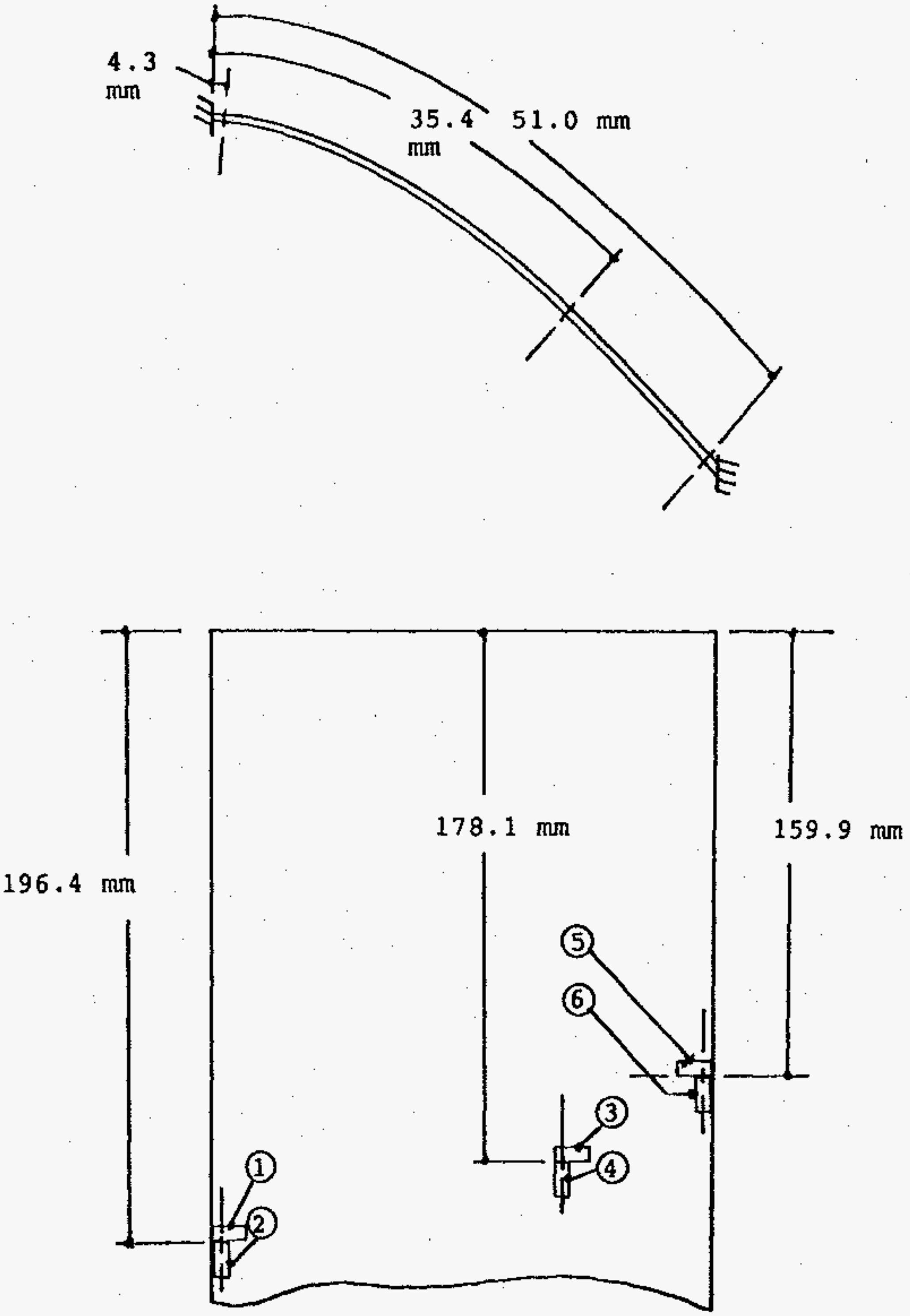


Fig.4. Strain Gage Locations

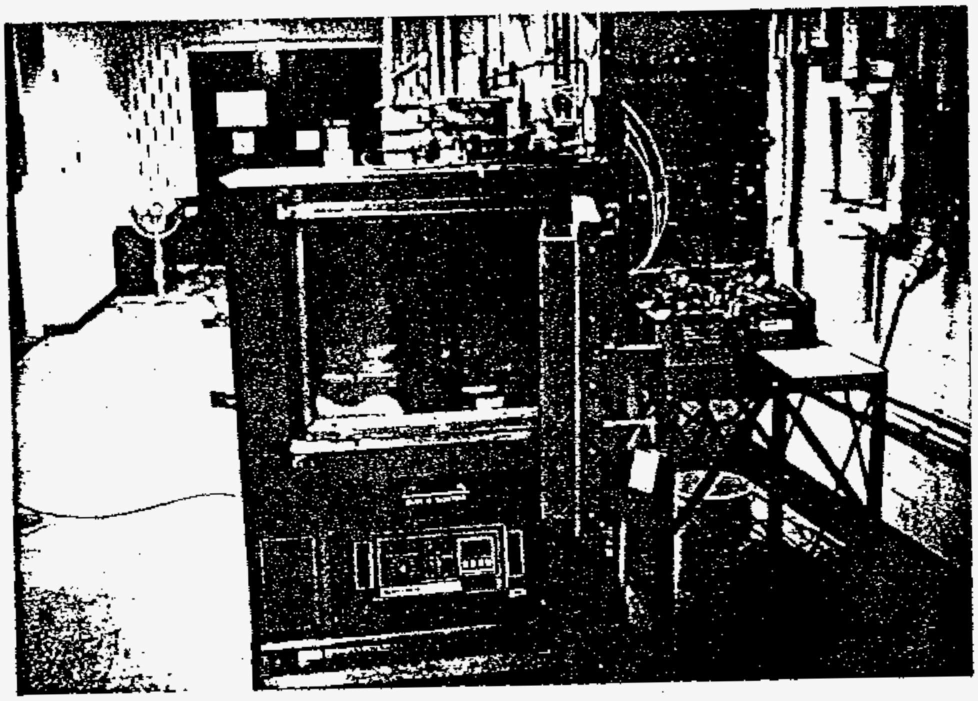


Fig.5. Assembled Test Element

As would be expected, the primary stress in the longitudinal direction due to the pressure load only was small and, when summed with the secondary stress in the longitudinal direction, had little effect on the principal stress in that direction. The more critical principal stress affecting plate failure occurred in the span direction where both the primary and secondary stresses had significant effects on this principal stress.

Of all the test points, the strain readings from gages 5 and 6, Fig.4, located on the plate with the convex exterior surface yielded the largest principal stresses. Referencing this test point in the span direction, the primary stress resulting from the pressure load only, the secondary stress resulting from the thermal load only, and the combined stress resulting from the combined pressure and thermal load are shown in Fig.6. The failure point noted in Fig.6 occurred with the thermal load already in place and after a test pressure of 275.8 KPa had been applied but before a test pressure of 344.7 KPa was reached. When the plates failed, the pressure load was still contained; however, each plate had a large bulge outward from the space between the plates and extended the length of the plate. Had this failure occurred in an operating reactor core some fuel plates would have made contact and "plate burn out" would have resulted. Examining Fig.6, it can be seen that by adding the stresses produced only by the pressure load to the stresses produced only by the thermal load yields essentially the same stress values realized when the loads were combined and the stresses evaluated. The secondary stress load did not relax as the combined stress level approached the material yield of 55 MPa. Also it is noted that when the pressure load of 344.7 MPa was applied between the plates that had no thermal load, no failure was evident. However, when this pressure load was applied to the plates that already had a thermal load, plate failure occurred. Thus, the thermal load did not relax sufficiently (if at all) during material yield to prevent failure.

Calculated stresses at the other test points had different magnitudes but the interaction of the stresses was the same. The addition of the stress from the pressure only data to the stress from the temperature only data gave essentially the same value as the stress from the combined loads. Since the results were repetitive of the results already presented in this paper, they are not included.

CONCLUSION

The purpose of this experiment was to examine the rationale of weighing the secondary (thermal) stresses, which result from reactions in the fuel plates, less than the primary (pressure) stresses, which are related to the coolant flow velocity between the plates. These tests indicate that, for this application of thin aluminum fuel plates, cooled through flow in narrow channels on both sides of a plate, the primary and secondary stresses should be weighted the same.

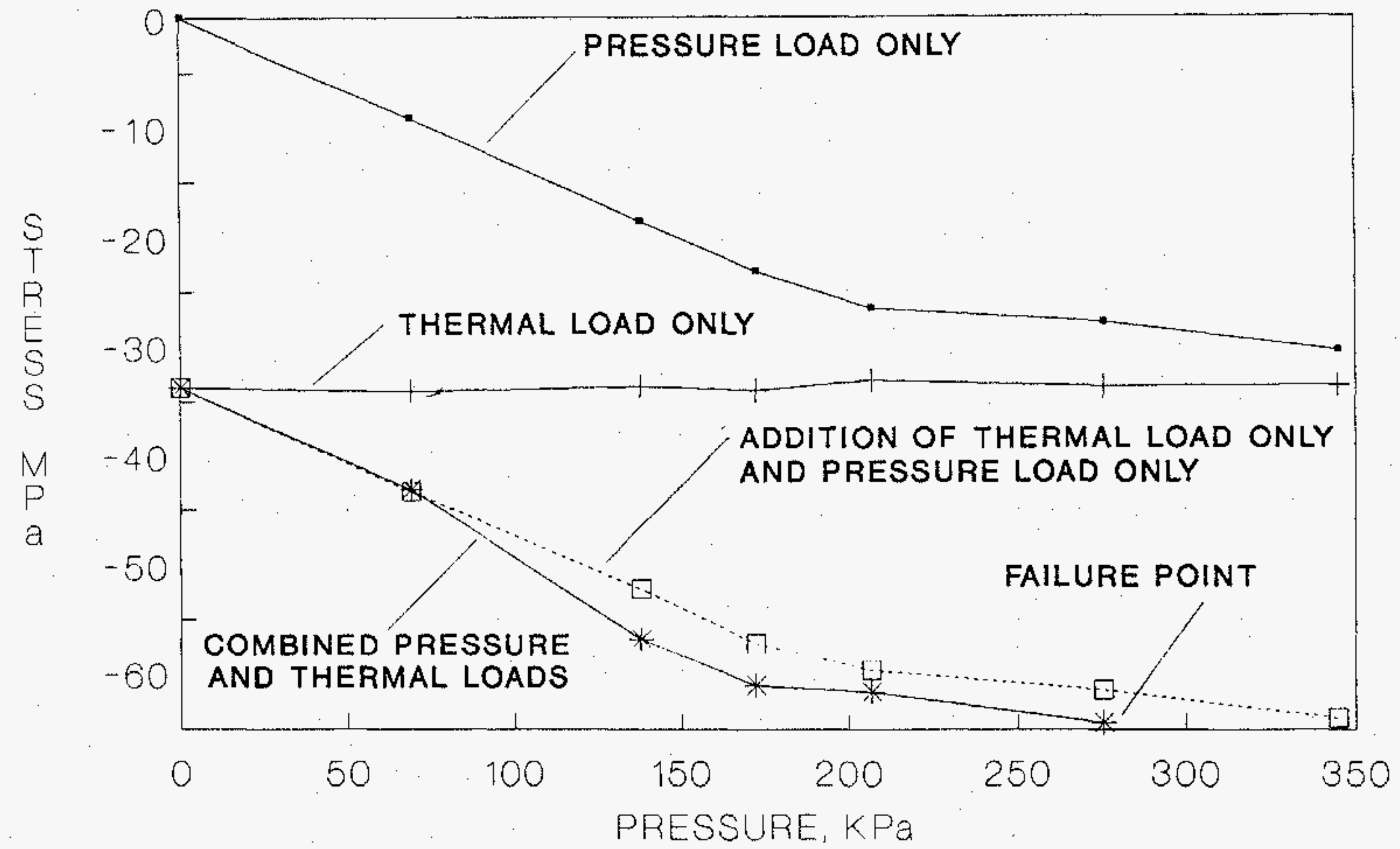


Fig. 6 Span Stress From Strain Gages
5 and 6

REFERENCES

[1]. C.D. West, "Overview of the ANS Project", Trans. Am. Nucl., Soc., 57,288-289 (1988).

[2]. ASME Boiler and Pressure Vessel Committee, "ASME Boiler and Pressure Vessel Code, Section III: Division I", The American Society of Mechanical Engineers, New York, New York, 1992.

[3]. W.F. Swinson, R.L. Battiste, C.R. Luttrell, G.T. Yahr, "An Experimental Investigation of the Structural Response of Reactor Fuel Plates", Experimental Mechanics, Vol.35-No.3, Sept. 1995, pp.212-215.