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INTRODUCTION

Fibrous composite materials like graphite/polyimide are light, stiff, and strong. They have great potential for reducing weight in aircraft structures. However, fibrous composites are usually notch sensitive and lose much of their strength when damaged. In the reference, buffer strips have been shown to greatly improve the damage tolerance of graphite/epoxy laminates loaded in tension.

The purpose of the present investigation was to test the buffer strip configuration at elevated temperature. Accordingly, graphite/polyimide buffer strip panels were made and tested to determine their residual strength at ambient and elevated (177°C) temperature. Each panel was cut in the center to represent damage. Panels were radiographed and crack-opening displacements were recorded to indicate fracture, fracture arrest, and the extent of damage in the buffer strip after arrest. One layup was used: $[45/0/-45/90]_{2S}$. All panels had the same buffer strip spacing and width. The buffer strip material was 0° S-glass/PMR-15. The buffer strips were made by replacing narrow strips of the 0° graphite plies with strips of the 0° S-glass on either a one-for-one or a two-for-one basis. Half of the panels were heated to 177±3°C before and during the testing. Elevated temperature did not alter the fracture behavior of the buffer configuration.

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EXPERIMENTAL PROCEDURES

Materials and Specimens

The specimens were made with Celion 6000/PMR-15 graphite/polyimide unidirectional tape. One basic layup was used: a 16-ply, quasi-isotropic layup, $[45/0/-45/90]_{2S}$. (The stacking sequence was 45/0/-45/90/45/0/-45/90/90/-45/0/45/90/-45/0/45.) Each panel had four evenly-spaced buffer strips parallel to the loading direction. The buffer strips were made from S-glass/PMR-15 tape. One side of each panel was made flat (see fig. 1).

The S-glass buffer strips were made by replacing narrow strips of the 0° graphite plies with strips of 0° S-glass on a one-for-one or a two-for-one basis. (The cross-section in figure 1 illustrates a two-for-one replacement.) Only the 0° graphite plies were interrupted by the buffer material; the ±45° and 90° graphite plies were continuous throughout the panels.

All of the panels were made with 5-mm-wide buffer strips spaced 20 mm apart (see fig. 1). Six panels were made with buffer strip replacement on a one-for-one basis, and six panels were made with buffer strip replacement on a two-for-one basis. The length of the test section of all panels was greater than twice the panel width.

Slits of 10 mm were cut through each panel to represent damage (see fig. 1). The slits were located at the center of each panel. No buffer strips were cut.

Small coupon-type specimens were also made to measure ultimate tensile strength, moduli, and fracture toughness. These were tested at room and elevated (177±3°C) temperature.

Test Procedures and Equipment

The panels were loaded to failure in uniaxial tension at a rate of about 1333 N/s. They were tested in servo-controlled, closed-loop testing machines with load as the feedback signal. Half of the panels were tested at room temperature and half were tested at the elevated temperature. The specimens tested at elevated temperature were heated in an oven before being loaded and were pulled to failure while the test section was still in the oven with the temperature at 177°C. The specimens were heated to 177°C for at least an hour before the testing began to insure an equilibrium temperature state within the oven. The oven itself was mounted on the test stand and closed around the test section of the specimen. This allowed continuous application of heat while the specimen was being loaded to failure. The outside dimensions of the oven were approximately 280 mm by 230 mm by 260 mm.

Loads, strains, and the opening displacement of the slit (commonly called crack-opening displacement or COD) were recorded on a digital data acquisition system. Frequently, at audible and visual evidence of crack extension during the room temperature tests, the loading was stopped and the region containing the slit and the two center buffer strips was radiographed. A dye-penetrant, zinc dioxide, enhanced the image of the damaged area. It was not possible to radiograph the specimen during the high-temperature tests because it was surrounded by the oven. A method to measure the COD while the specimen remained in the oven had to be devised. A ring gage device (see fig. 2) was used. The ring was approximately 31 mm in diameter and could easily operate in the confined space of the oven. It was designed to withstand temperatures in excess of 260°C. The ring gage was also used to measure COD in the room temperature tests to insure consistent results.

RESULTS AND DISCUSSION

Some typical test results for buffer strip panels tested at room and elevated temperature are shown in figure 3. The remote strain is plotted against slit length for four panels. The estimated failing strain of a sheet without buffer strips is shown for comparison. Coupon data from plain laminates were used to make the estimate. The room temperature results (open symbols) showed crack arrest, as expected, like the results described in the reference. Fracture initiated at about the failing strain of a plain sheet; the failing strains of the buffer strip panels exceeded substantially the strain at which a plain sheet would have failed. Crack arrest was also seen in the elevated temperature tests (solid symbols). These failing strains were much higher than the estimated failing strain of a plain sheet. In the high-temperature tests, however, the crack did not run into the buffer strip in a distinct jump as it did in the room temperature tests. Cracks grew stably until the crack tip reached the buffer strip; then, with increasing load, the panel failed. All of the panels tested behaved like those shown in figure 3. The arrested fractures and radiographs were like those described in the reference. The jumps in COD and radiographs clearly showed fracture initiation and arrest for the room temperature tests. But in the elevated temperature tests there were no distinct jumps in COD; the elevated temperature COD curve seemed to mirror the room temperature curve. This is shown in figure 4 for a buffer strip panel with two-for-one replacement. In the room temperature test (open symbols) distinct jumps in the COD indicated crack growth and damage. In the high-temperature test (solid symbols) there were no jumps in the COD, but the curve has nearly the same slope as the room temperature curve. These results are typical of all panels tested.

EFFECT OF NUMBER OF BUFFER PLIES AND ELEVATED TEMPERATURE

Figure 5 illustrates the effect of the number of buffer plies and elevated temperature on the ultimate strength of the buffer strip panels. The estimated failing stress for a plain laminate with a crack equal to the buffer strip spacing is shown for comparison. Results for graphite/epoxy buffer strip panels with the same specimen configuration (from the reference) are also shown. Each data point represents the average of two or three tests.

The remote failing stresses of all panels in figure 5 exceeded considerably the estimate for the panel with no buffer strips. Clearly, the buffer strips arrested crack growth. The strengths of the panels with two-for-one buffer strip replacement were less than the strengths of the one-for-one replacement panels. This contradicts results reported in the reference. However, the difference is small (~5 percent) and, since the failing stresses of both configurations are close to the net-section utlimate strength, this difference may not be significant.

Both buffer strip configurations show lower failing stresses for the tests run at 177°C. Two plots of stress vs. strain are shown in figure 6: (1) room temperature results and (2) elevated temperature results. The results shown are typical for a buffer strip panel with two-for-one replacement. As can be seen in figure 6, the failing strains for the tests run at the elevated temperature are slightly higher (~1 percent) than the failing strains of the room temperature tests. However, the failing stresses are significantly lower for the high-temperature tests. The elevated temperature causes a softening of the laminate, resulting in higher strains but lower strengths. In effect, the higher temperature causes a reduction in the apparent modulus of the panel. The same trend was observed for the plain graphite/polyimide coupon specimens.

To determine the effect of elevated temperature on the behavior of the buffer strip material, some unidirectional S-glass/PMR-15 specimens were tested. The elevated temperature had virtually no effect on the ultimate strength of the S-glass, although the high temperature did increase the failing strains. This is consistent with the material behavior in the buffer strip panel.

CONCLUDING REMARKS

Graphite/polyimide panels with buffer strips parallel to the loading direction were tested to measure the effect of elevated temperature (177±3°C) on their residual tension strength with crack-like damage. Panels were made with a $[45/0/-45/90]_{2S}$ layup. The buffer strips were made by replacing narrow strips of the 0° graphite plies with strips of 0° S-glass on either a one-for-one or a two-for-one basis. The panels were cut at the center between buffer strips to represent a crack.

Crack arrest was observed in all tests. The remote failing stresses of all buffer strip panels were significantly higher than the estimated strength of a plain sheet. Elevated temperature did not alter the fracture arrest behavior of the buffer strip configuration. The ultimate residual strengths were reduced by the elevated temperature. The strengths of the panels with two-for-one buffer strip replacement were slightly lower than the strengths of the panels with one-for-one replacement. However, the strengths in all cases were very close to the net-section ultimate strength.

REFERENCE

Poe, C. C., Jr.; and Kennedy, J. M.: An Assessment of Buffer Strips for Improving Damage Tolerance of Composite Laminates. J. of Composite Materials Supplement, vol. 14, 1980, pp. 57-70.

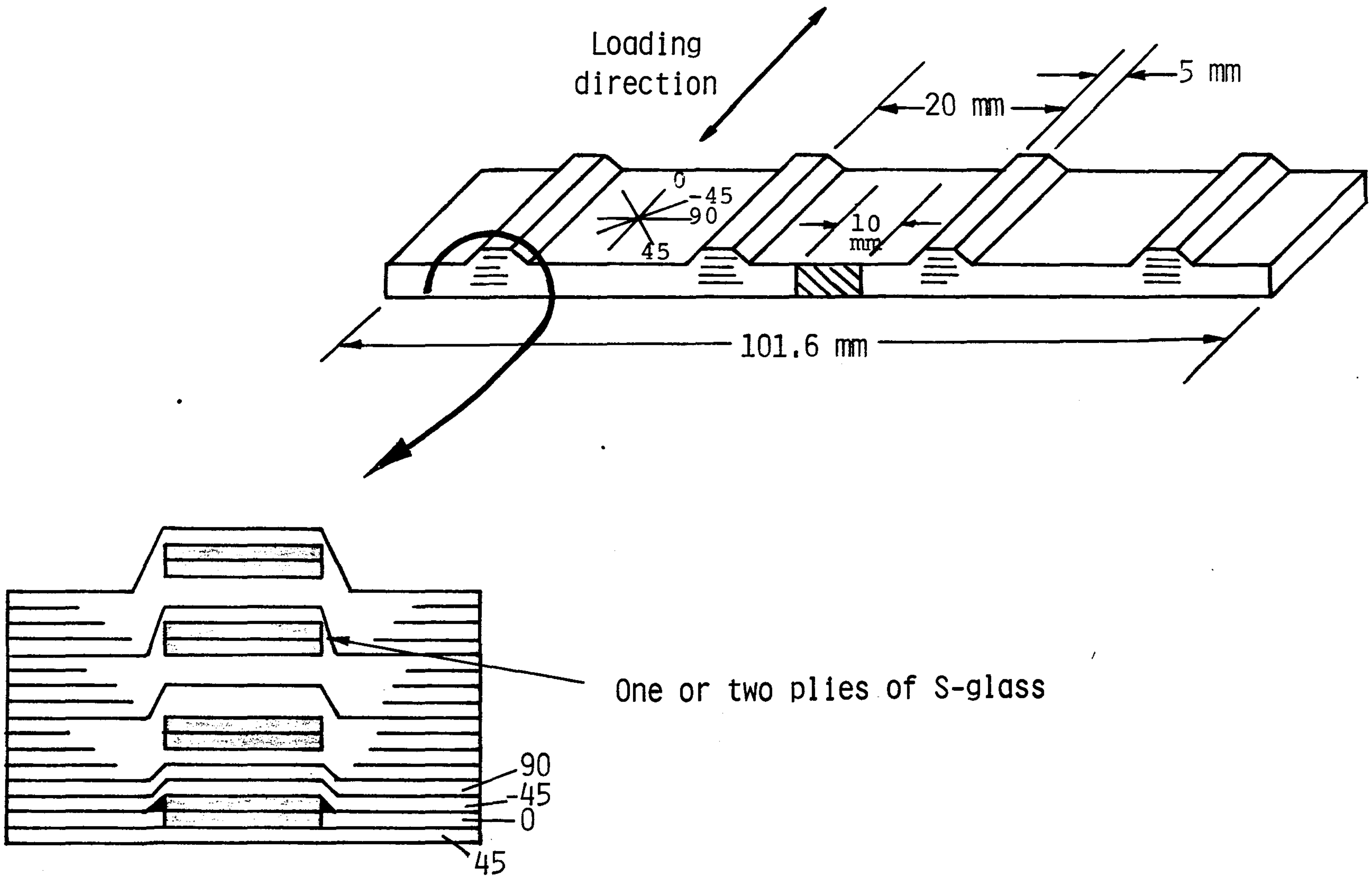

Figure 1.- Buffer strip configuration.

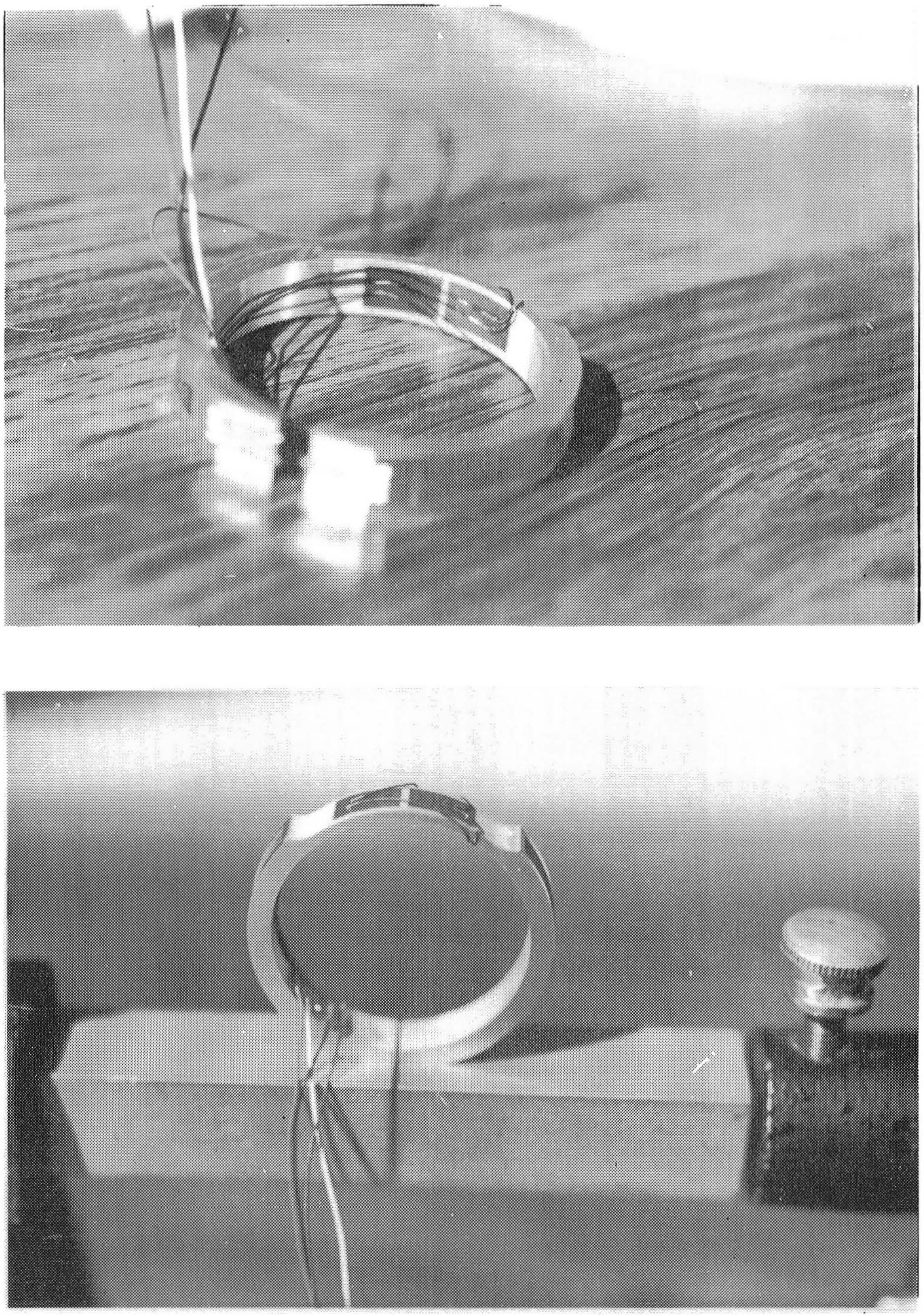

Figure 2.- Ring device used to measure crack-opening displacement.

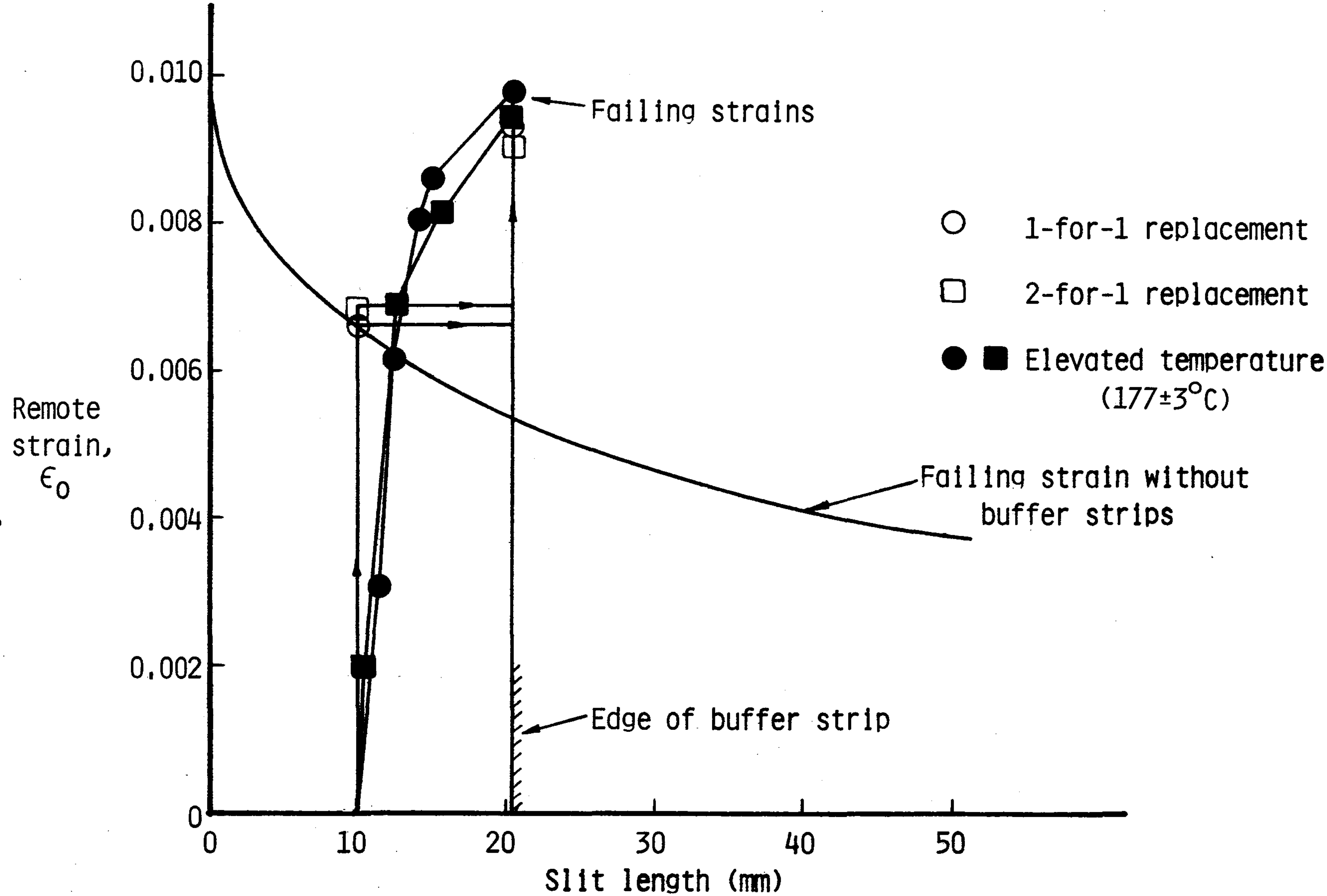

Figure 3.- Typical fracture arrest results for $[45/0/-45/90]_{2S}$ graphite/polyimide panels with S-glass buffer strips.

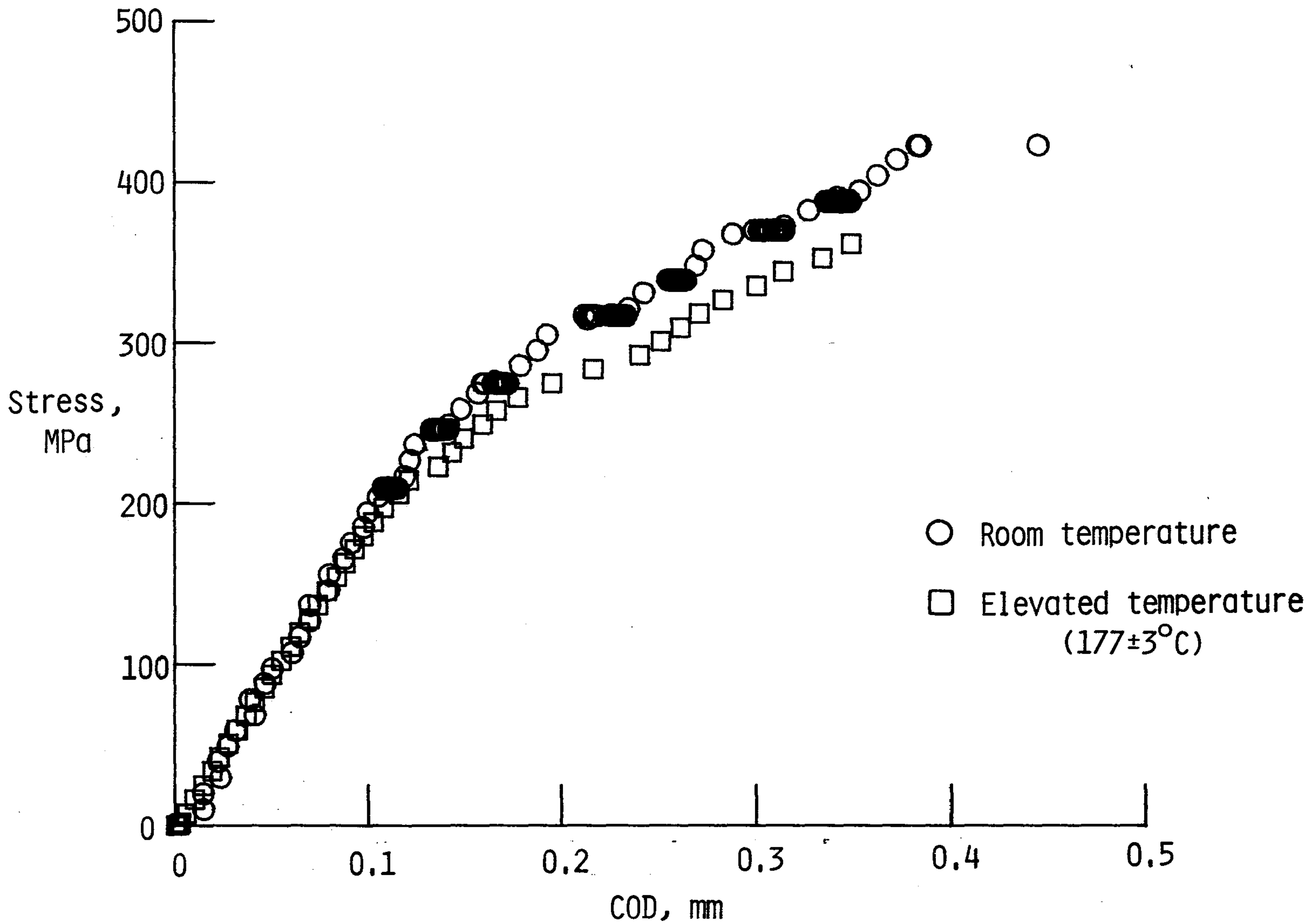

Figure 4.- Crack-opening displacement for $[45/0/-45/90]_{2S}$ graphite/polyimide panels with S-glass buffer strips.

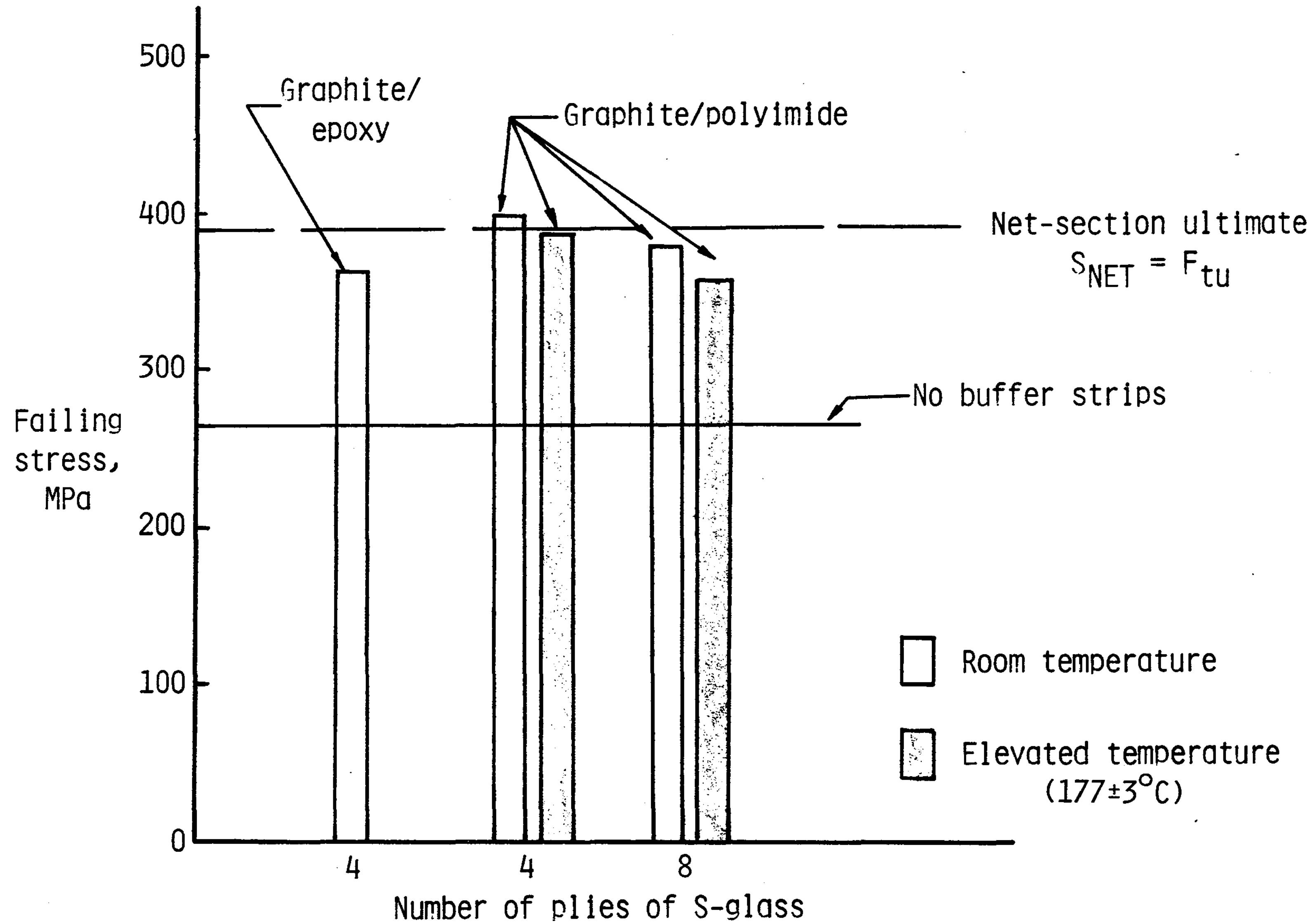

Figure 5.- Strengths of $[45/0/-45/90]_{2S}$ graphite/epoxy and graphite/polyimide panels with S-glass buffer strips.

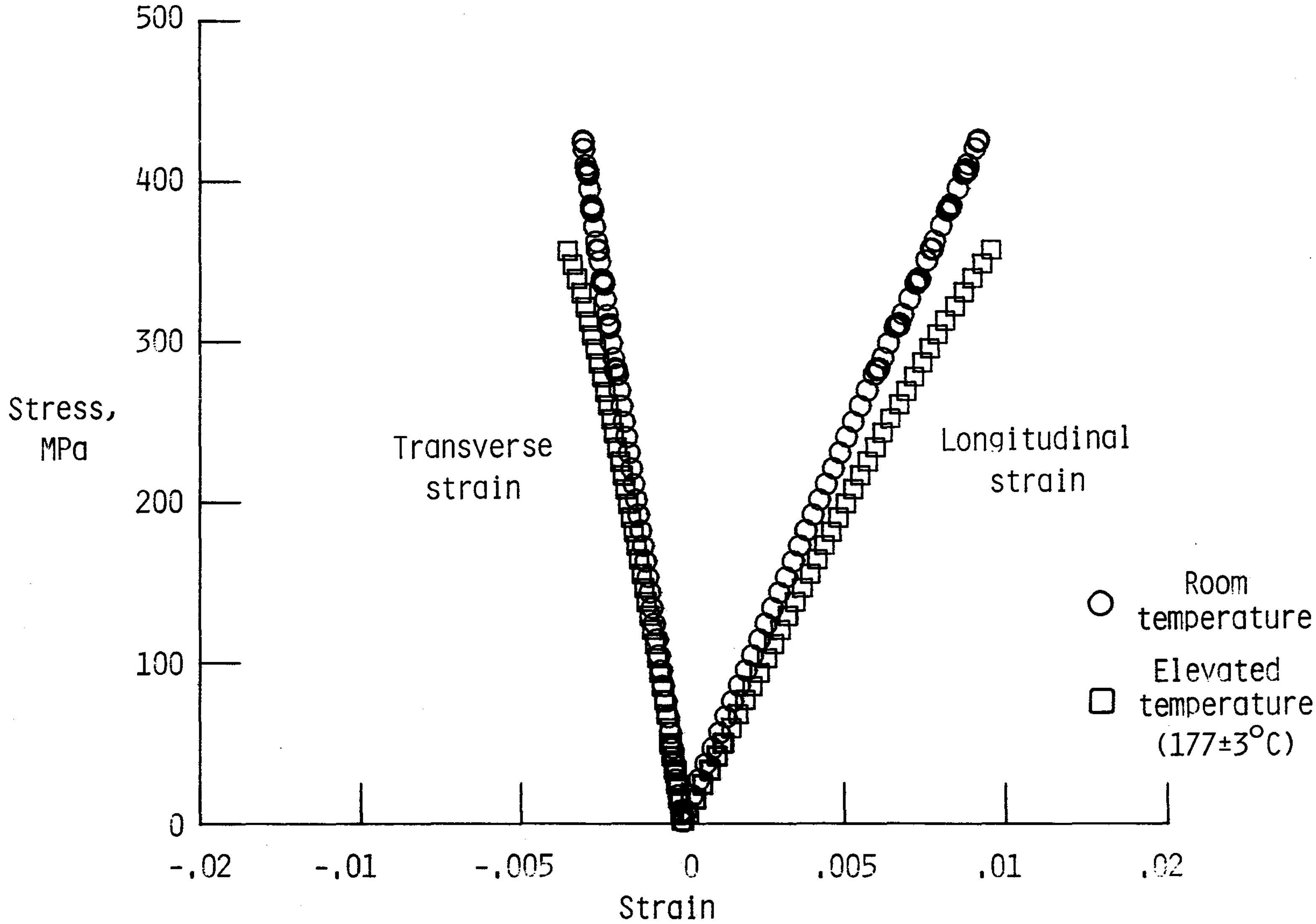

Figure 6.- Typical stress vs. strain for $[45/0/-45/90]_{2S}$ graphite/polyimide panels with S-glass buffer strips.

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15. Supplementary Notes

16. Abstract

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