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EFFECTS OF MOISTURE, ELEVATED TEMPERATURE, AND FATIGUE LOADING ON THE BEHAVIOR OF GRAPHITE/EPOXY BUFFER STRIP PANELS WITH CENTER CRACKS

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SUMMARY

The effects of fatigue loading combined with moisture and heat on the behavior of graphite/epoxy panels with either Kevlar-49 or S-glass buffer strips were studied. Buffer strip panels, that had a slit in the center to represent damage, were moisture conditioned or heated, fatigue loaded, and then tested in tension to measure their residual strength. Panels were made with a $[45/0/-45/90]_{2s}$ layup with either Kevlar-49 or S-glass buffer strip material. The buffer strips were parallel to the loading direction and were made by replacing narrow strips of the 0-degree graphite plies with Kevlar-49/epoxy or S-glass/epoxy on a one-for-one basis. The panels were subjected to a fatigue loading spectrum with two levels of maximum strain and five different durations of the fatigue spectrum. One group of panels was preconditioned by soaking in 60^{0} C water to produce a 1% weight gain then tested at room temperature. One group was heated to 82^{0} C during the fatigue loading. Another group was moisture conditioned and then tested at 82^{0} C. Also, panels from each group were tested to determine their residual strengths without fatigue loading.

As expected, for the panels without fatigue loading, the buffer strips arrested the crack growth and increased the residual strengths significantly over those of laminates without buffer strips under all conditions. However, for the S-glass buffer strip panels with moisture conditioning, the increase in the residual strength was less than for the other conditions.

For the panels subjected to fatigue loading, the residual strengths were not significantly affected by the fatigue loading, the number of repetitions of the loading spectrum, or the maximum strain level. The moisture conditioning reduced the residual strengths of the S-glass buffer strip

panels by 10 to 15% below the ambient results. The moisture conditioning did not have a significant effect on the Kevlar-49 panels. The heating did not affect the panel strengths of the buffer strip panels for either buffer material. The stiffnesses of the panels were not significantly affected by the fatigue loading, the moisture, the elevated temperature, or the combination of moisture and elevated temperature. The fatigue cycling also did not produce any damage growth at the crack tips.

These results show that the improved fracture strength produced by the buffer strip configuration is not significantly degraded by fatigue loading, by elevated temperature, or by moisture conditioning, except for the moisture-conditioned S-glass buffer material.

INTRODUCTION

The high strength-to-weight and stiffness-to-weight ratios of advanced fiber-reinforced composites, such as graphite/epoxy, make them one of the outstanding primary structural materials in the aeronautical industry. Despite many efforts in the past to understand their mechanical performance, there still remain important technical questions to be answered before extensive use of composite materials will occur. One such question concerns the long-term mechanical performance under conditions of moisture and elevated temperatures. When subjected to fatigue loading, composites can exhibit several modes of damage including delamination, fiber failure and matrix cracking. Moisture and elevated temperature can also effect damage development and propagation.

In static tests, the buffer strip configuration has been shown to greatly improve the damage tolerance of graphite/epoxy panels subjected to tension loads (ref. 1). The buffer strips act to contain the damage and result in much higher residual strengths for cracked or damaged panels. In ref. 1, the fractures in the buffer strip panels were shown to initiate at approximately the failing strain of a plain panel (i.e., a panel without buffer strips), run into the buffer strips, and stop. The load was increased and the panels eventually failed at strains higher than those at which the fractures initiated and at which the plain panel would have failed.

In earlier work (ref. 2), the effects of fatigue loading on the behavior of graphite/epoxy panels with either Kevlar-49 or S-glass buffer strips were studied. The results presented in reference 2 are for unconditioned buffer strip panels tested at room temperature. Herein, the results presented in reference 2 will be referred to as the ambient results. At ambient conditions, the residual strengths of the panels were not affected by the fatigue loading. Also, the stiffnesses of the panels were not significantly changed by the fatigue loading. In all cases, the buffer strips arrested the cracks and increased the residual strengths significantly over those of laminates without buffer strips.

The purpose of the present investigation was to study the effects of fatigue loading, elevated temperature, and moisture on the behavior of graphite/epoxy buffer strip panels. Accordingly, graphite/epoxy buffer strip panels were subjected to a fatigue loading spectrum and then statically tested in tension to determine their residual strengths. One layup was used, $[45/0/-45/90]_{2s}$, with two different buffer strip materials: Kevlar-49 or S-glass. Some panels were soaked in water until a weight gain of 1% was reached; some were heated in an oven during the fatigue and static loading portions of the tests; others were soaked in water and heated during loading. Each panel was cut in the center to represent damage. Panel strains and crack-opening-displacements were measured to indicate panel stiffness and the extent of damage at the crack tips.

The residual strengths of the fatigued panels are compared to the residual strength of a buffer strip panel without spectrum loading and to the residual strength of a graphite/epoxy panel without buffer strips. Comparisons were made for both buffer materials for moisture conditioning, heat and the combination of moisture and heat. The effects of fatigue cycling, moisture, and heat on the panel stiffness and the crack-tip damage state were periodically measured during the fatigue cycling.

EXPERIMENTAL PROCEDURES

Materials and Specimens

The panels were made with T300/5208 graphite/epoxy in a 16-ply quasi-isotropic layup, $[45/0/-45/90]_{2s}$. Each panel had four evenly spaced buffer strips parallel to the load direction. The panel configuration is shown in Figure 1. The buffer strips were made from two different materials: Kevlar-49/5208 or S-glass/5208 tape. All the panels were 102 mm wide constructed with 5-mm-wide buffer strips spaced 20 mm apart, with slits 10 mm long and 0.020 (±0.002) mm wide cut in the center of the panel to represent damage (see Fig. 1). The buffer strips were made by replacing narrow strips of the 0-degree graphite plies with strips of either 0-degree Kevlar-49 or S-glass on a one-for-one basis. The panels used in the present study were made from the same batch of material and in the same configuration as those used in ref. 2.

Moisture and Heat Conditioning

One group of panels was soaked in water before testing. To accelerate the absorption rate, the water was held at a temperature of 60^{0} C. The panels remained in the heated water until a weight gain of 1% was measured. At that time, the panels were removed from the water, weighed, and stored in watertight containers until testing. As the test time was relatively short, no attempt was made to maintain the moisture level during testing. Strain gages were mounted on these panels with a coating to prevent debonding of the strain gages during soaking. However, the coating was not very effective; some of the strain gages did debond during the moisture conditioning.

For the elevated temperature tests, an oven was mounted on the test stand and closed around the test section of the panel. Approximately 178 mm of the panel length was enclosed in the oven. The panels were heated to 82^{0} C for at least an hour before testing to insure thermal equilibrium during each test. The temperature was held constant for the duration of the test.

Test Procedures and Equipment

The panels were tested under a fatigue spectrum loading. MINITWIST (ref. 3), a shortened version of a standardized load program for the wing lower surface of a transport aircraft, was chosen to provide a realistic load history for the panels. The complete MINITWIST spectrum contains 4000 flights with each flight consisting of about 15 load cycles on average. The maximum load in the MINITWIST spectrum occurs only once. The tests were run at approximately 5 Hz. One repetition of the MINITWIST spectrum took approximately 4 hours.

Tables 1 and 2 show the test matrices that were used for the panels containing the Kevlar-49 and S-glass buffer strips, respectively. Each group of panels made with the Kevlar-49 or the S-glass buffer strip material was divided into three sets: (1) panels that were conditioned by soaking in heated (60^{0} C) water; (2) panels that were heated to 82^{0} C in an oven before and during the spectrum loading; and (3) panels that were conditioned by soaking in heated water and heated in the oven before and during the spectrum loading. Within each set, several different continuous repetitions (as shown in Tables 1 and 2) of the MINITWIST spectrum were used. Additionally, two values of the maximum strain level in the spectrum were used. An average strain of 0.005 is often used as the ultimate design strain in wing panels (ref. 4); thus, the values of 0.005 and 0.006 were chosen as two realistic values of ultimate design strain for an actual structure. The corresponding values of maximum strain used in the MINITWIST spectrum were 0.0035 and 0.0042. Guide plates were mounted on the panels during the fatigue loading to prevent compression buckling during the air-ground-air cycle of the MINITWIST spectrum. After the fatigue loading, all panels were statically loaded in tension to failure to determine their residual strengths.

Periodically during the fatigue cycling in all tests, the spectrum loading was stopped and the panel was statically loaded in tension to the prescribed maximum strain. During these static load segments, load versus remote strain, load versus strain in the buffer strip next to the crack tip and load versus crack-opening-displacement (COD) were recorded. Strain gages were located on the panels as indicated in Figure 1. The COD was measured using a ring gage. These data was used to determine if the fatigue loading had produced any change in the panel stiffness or resulted damage growth at the crack tip as measured by the slope of the load-strain curves or the load-COD curves.

A number of plain graphite/epoxy tensile coupons and center-cracked fracture specimens were made at the same time and from the same batch of material as the buffer strip panels. Some of these specimens were moisture conditioned or heated the same as the buffer strip panels and then tested statically in tension to determine what effects, if any, the moisture or heat had on the laminate. Tensile coupons 25.4-mm wide were tested to determine the longitudinal modulus. Fracture specimens 102-mm wide with a center crack equal in length to the buffer strip spacing were tested to determine the residual strength of the plain graphite/epoxy panels.

RESULTS AND DISCUSSION

Plain Panels

As previously mentioned, a number of plain graphite/epoxy tensile coupons and center-cracked fracture specimens were made and tested statically under the same conditions as the buffer strip panels. Table 3 shows results from these tests. For comparison, Table 3 also shows the modulus and residual strength for the room temperature tests reported in ref. 2. The results in Table 3 show that neither the moisture nor the heat had an effect on the longitudinal modulus of the material. The heat did not have a significant effect on the residual strength of the plain panel; the moisture conditioning, however, increased the residual strength of the plain panel slightly (less than 5%) over the room temperature value.

Residual Strengths

Kevlar-49 Buffer Strip Material. Figure 2 shows the residual strengths for the Kevlar-49 buffer strip panels, with and without fatigue loading. The results plotted are the averages for each test condition of the test data shown in Table 1. Also shown are the residual strengths of the plain graphite/epoxy panels without fatigue loading.

For the panels without fatigue loading, Figure 2 shows that, as expected, the residual strengths of the buffer strip panels were significantly higher (35%) than the residual strengths of the plain panels. The residual strengths of the moisture-conditioned buffer strip panels were slightly below the residual strengths of the heat-conditioned buffer strip panels.

For the buffer strip panels with fatigue loading, Figure 2 compares the residual strengths for various numbers of repetitions of the MINITWIST spectrum as well as for the two maximum strain levels used. The figure shows that neither the level of the maximum strain nor the number of repetitions of the MINITWIST spectrum had a significant effect on the residual strengths of the buffer strip panels. In the majority of the cases, the residual strengths of the fatigued panels were only slightly below the residual strengths of the Kevlar-49 buffer strip panels without fatigue loading.

Figure 2 also shows that moisture conditioning, heat, or the combination of both had virtually the same effect on the residual strengths of the panels. On average, the residual strengths shown in Figure 2 are slightly higher than the results for ambient conditions (ref. 1). For all conditions, the failing strengths were higher than for similar graphite/epoxy panels without buffer strips; thus, the fractures were arrested by the buffer strips under all conditions.

Table 1 also lists the residual strengths and failure strains of the Kevlar-49 buffer strip panels for each test condition. The residual strengths of Kevlar-49 buffer strip panels with moisture or heat, but without fatigue loading, are also given in Table 1. Such strengths were not measured for panels with combined moisture and heat.

<u>S-Glass Buffer Strip Material</u>. Figure 3 shows the residual strengths for the S-glass buffer strip panels, with and without fatigue loading. Also shown in the figure are the residual strengths of the plain graphite/epoxy panels without fatigue loading.

For the panels without fatigue loading, Figure 3 shows that, as expected, the residual strengths of the buffer strip panels were significantly higher than the residual strengths of the plain panels. For the S-glass buffer strip material, the residual strengths of the moisture-conditioned buffer strip panels were well below (by 11%) the residual strengths of the heated buffer strip panels. (Although not shown in the figure, the residual strength of a panel tested under ambient conditions is approximately equal to the heated results.) Thus, although the fractures were arrested by the buffer strip, for the moisture conditioned panels, the effectiveness of the buffer strip configuration was reduced compared to the heated or ambient results.

For the panels with fatigue loading, Figure 3 compares the residual strengths for various numbers of repetitions of the MINITWIST spectrum as well as for the two maximum strain levels used. The figure shows that within each test condition neither the level of the maximum strain nor the number of repetitions of the MINITWIST spectrum had a significant effect on the residual strengths of the buffer strip panels. For the heated panels, the residual strengths of the fatigued panels did not differ significantly from the strength of the panels without fatigue loading. The residual strengths of the moisture-conditioned panels were lower (by up to 14%) than the residual strength of the moisture conditioned S-glass buffer strip panel without fatigue loading.

Figure 3 shows that the moisture conditioning had a marked effect on the residual strengths of the S-glass buffer strip panels. On average, the results shown for the moisture-conditioned S-glass panels are approximately 15% below the results for the heated S-glass panels and 10% below results for ambient conditions (ref. 2). A similar reduction is seen for the panels that were moisture conditioned and heated. The reduction for the S-glass buffer strip panels, with and without fatigue, is not entirely unexpected, since as demonstrated in reference 5, the ultimate tensile strength of a E-glass/1009 resin system decreased continuously with increasing amounts of water absorption. For the heated panels, the results shown in Figure 3 are approximately equal to the ambient results (ref. 2). As before, the failing strengths of the S-glass buffer strip panels were higher than for similar graphite/epoxy panels without buffer strips; thus, the fractures were arrested by the buffer strips under all conditions. Although for the S-glass buffer strip material, the moisture conditioning significantly reduced the effectiveness of the buffer strip.

Table 2 lists the residual strengths and the failure strains of the S-glass buffer strip panels for each test condition. The residual strengths of the S-glass buffer strip panels with moisture or heat, but without fatigue loading, are also given in Table 2.

Stiffness

During the fatigue cycling, load versus strain plots were made periodically to monitor the panel stiffness. Figures 4 and 5 show two sets of typical plots that were made for panels that were moisture conditioned. Figure 4 shows a series of strain versus load plots for a Kevlar-49 buffer strip panel with a maximum strain level of 0.0035 and Figure 5 shows a series of strain versus load plots for a S-glass buffer strip panel with a maximum strain level of 0.0042. Five repetitions of the MINITWIST spectrum were applied to each panel. (Notice that an offset of 10 kN is used for each subsequent plot in Figures 4 and 5.) These plots are typical of all the test results.

As mentioned earlier, one repetition of the MINITWIST spectrum simulates 4000 flights for a transport wing structure and during the normal MINITWIST cycle, the maximum load is applied only once. As shown in the figure, data was plotted before the spectrum loading began (0 flights) then the fatigue cycling was stopped and data was plotted after 1 repetition (4000 flights), after 2 repetitions (8000 flights), after 3 repetitions (12000 flights), after 4 repetitions (16000 flights), and after 5 repetitions (20000 flights) of the spectrum. In this test program, each buffer strip panel was loaded to the maximum load level during each periodic plot such as those shown in Figures 4 and 4. This means that the maximum load level was applied several more times than called for in the MINITWIST spectrum itself. For the results shown in Figures 4 and 5, the maximum load was applied six times beyond what was applied in the repetitions of MINITWIST. The number of extra maximum loads applied depended upon the number of times the fatigue cycling was interrupted to statically load the panel to the prescribed maximum strain level and ranged from two to six. These extra applications of maximum load produced a more severe test of the panel than the spectrum loading alone would have.

The moisture conditioning, the heat, or the combination of moisture and heat did not affect the load-strain behavior of the buffer strip panels. The periodic load versus strain plots were nearly identical for all conditions, and were very similar to the ambient results given in ref. 2. Thus, there was no change in the overall panel stiffness due to any of the test conditions. Although the water absorption caused a significant change in the residual strengths of the S-glass buffer strip panels, no change was seen in the stiffness of these panels. Reference 5 also observed no significant change in the modulus of the glass/epoxy due to water absorption.

Crack Opening Displacements

During the fatigue cycles, crack-opening-displacement (COD) versus load plots were made periodically to monitor the damage state at the crack tip. Figures 6 and 7 show two sets of typical COD versus load plots for panels that were moisture conditioned. The plots in Figures 6 and 7 are for the same panels used in Figures 4 and 5. The data shown in these plots are typical of the results for all the buffer strip panels. For the panel with the maximum strain level of 0.0035 (Figure 6), there was no indication of any damage growth; the slope of the COD-load plots remained constant. For the panel with the maximum strain level of 0.0042 (Figure 7), there was some damage growth at the crack tips, as indicated by the sharp jump in the COD versus load plot for the initial load segment (0 repetitions). However, there was no significant change in the slope of the subsequent plots nor in the slopes of the load versus strain plots shown in Figure 7. Thus, there was no change in the damage state at the crack tip. The jumps on the COD plots were seen only for the panels loaded to the maximum strain value of 0.0042 and only in the initial loading segment. There was no damage growth due to the fatigue loading. There was no indication of any initial damage growth for the panels with the maximum strain level of 0.0035.

Strains

The failing strains of the buffer strip panels are listed in Tables 1 and 2. The data given in these tables show that the majority of the actual failing strains of the panels were much higher than the assumed ultimate design strain levels of 0.005 and 0.006. The failing strains ranged from 1.1 to 1.5 times the design ultimate. The exceptions here were the S-glass buffer strip panels that had been moisture conditioned. The actual failing strains of those panels (see Table 2) were close to the assumed ultimate design strain of 0.006. Thus, except for the moisture-conditioned S-glass panels, the spectrum loading did not test the buffer strip panels as severely as it might have. The failing strains of the S-glass buffer strip panels subjected to moisture conditioning were also significantly lower than the ambient results (ref. 2). However, the failing strains of the rest of the panels were approximately equal to the ambient results reported in ref. 2.

CONCLUDING REMARKS

Graphite/epoxy buffer strip panels were tested to measure their residual tension strength after fatigue spectrum loading combined with moisture and heat. Panels were made with a $[45/0/-45/90]_{2s}$ layup. The buffer strips were made by replacing narrow strips of the 0-degree graphite plies with strips of either 0-degree Kevlar-49 or S-glass on a one-for-one basis. The panels had a slit in the center between buffer strips to represent damage.

The panels were subjected to a fatigue loading spectrum, MINITWIST, a shortened version of a standardized load program for the wing lower surface of a transport aircraft. Two levels of maximum strain were used in the spectrum with five different durations of the fatigue spectrum. One group of panels was preconditioned by soaking in heated water until a 1% weight gain was measured. One group was heated in an oven before and during the fatigue loading. Another group was moisture conditioned and heated. Buffer strip panels from each group were statically loaded in tension to failure to determine their residual strengths without fatigue loading. During fatigue loading, periodic plots of load versus strain and load versus crack-opening-displacements were made to monitor the panel stiffness and the damage state at the crack tip. After fatigue loading, all panels were statically loaded in tension to failure to determine their residual strengths.

As expected, for the panels without fatigue loading, the buffer strips arrested the crack growth and increased the residual strengths significantly over those of plain panels under all conditions. However, for the S-glass buffer strip panels with moisture conditioning, the increase in the residual strength was less than for the other conditions.

For the panels subjected to fatigue loading, the residual strengths were not significantly affected by the fatigue loading, the number of repetitions of the loading spectrum, or the maximum strain level. The moisture conditioning had a significant effect on the residual strengths of the S-glass buffer strip panels, reducing the residual strengths by 10 to 15% below the ambient results. The moisture conditioning increased the residual strengths of the Kevlar-49 buffer strip panels slightly over the ambient results. The heat increased the residual strengths of the buffer strip panels slightly over the ambient results for both buffer strip materials. The stiffnesses of the panels were not significantly affected by the fatigue loading, the moisture, the elevated temperature, or the combination of moisture and elevated temperature. The fatigue cycling also did not produce any damage growth at the crack tips.

These results show that the improved fracture strength produced by the buffer strip configuration is not significantly degraded by fatigue loading, by elevated temperature conditions, or by moisture conditions, except for the moisture-conditioned S-glass buffer material.

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Table 1. Residual strengths and failing strains for graphite/epoxy panels with Kevlar-49 buffer strips.

test condition	maximum strain ϵ	no. of repetitions of MINITWIST	residual strength (MPa)	failing strain
1% moisture, room temperature	0.0035	1	383	0.00800
		1	347	0.00780
		2	370	0.00780
		4	384	0.00820
		5	391	0.00800
	0.0042	3	391	0.00800
		4	350	0.00620
		5	389	0.00810
		5	368	0.00640
	static	0	394	*
82° C	0.0035	1	372	0.00770
		2	397	0.00860
		3	391	0.00820
	0.0042	1	370	0.00785
		2	357	0.00730
		2	381	0.00780
		3	402	0.00830
		3	347	0.00720
		5	355	0.00730
	static	0	411	0.00840
1% moisture, 82° C	0.0035	5	359	0.00840
	0.0042	5	374	0.00780

* Strain gages debonded before failure.

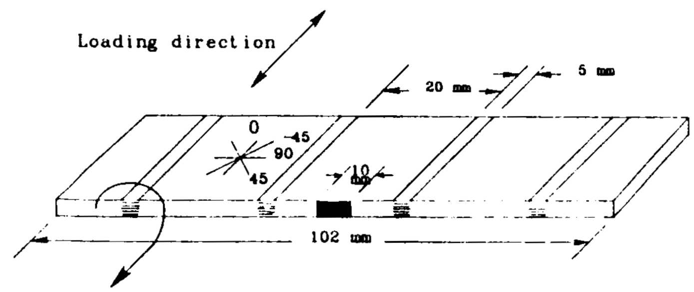
Table 2. Residual strengths and failing strains for graphite/epoxy panels with S-Glass buffer strips.

test condition	maximum strain ϵ	no. of repetitions of MINITWIST	residual strength (MPa)	failing strain
1% moisture, room temperature	0.0035	1	318	0.00640
		1	387	0.00850
		1	313	0.00625
		2	305	0.00620
		4	299	*
		5	305	0.00650
	0.0042	3	295	0.00630
		4	347	*
		5	346	0.00710
		5	297	0.00630
	static	0	344	*
82° C	0.0035	1	402	0.00805
		2	334	0.00680
		2	376	0.00790
		3	377	0.00770
	0.0042	1	358	0.00760
		1	400	0.00840
		2	334	0.00680
		3	367	0.00770
		3	337	0.00710
		5	387	0.00790
	static	0	386	0.00820
1% moisture, 82° C	0.0035	5	294	0.00580
	0.0042	5	308	0.00640

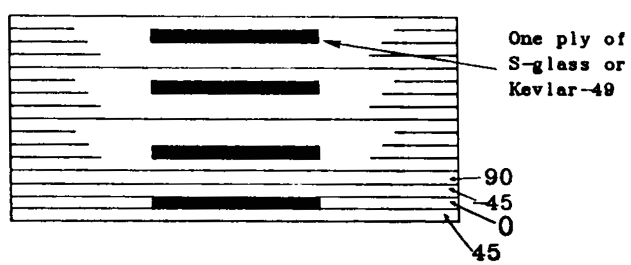
* Strain gages debonded before failure.

Table 3. Properties of $[45/0/-45/90]_{2s}$ graphite/epoxy laminate.

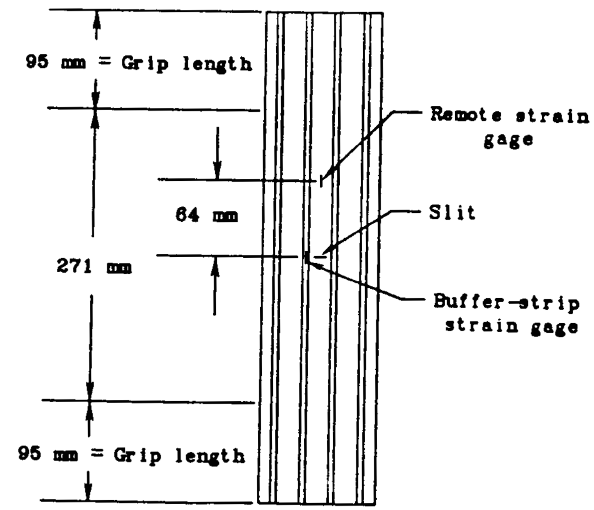
	25-mm tensile coupons	102-mm fracture specimens	
test condition	longitudinal modulus (GPa)	residual strength (MPa)	failing strains
room temperature	53.63	257	0.00418
1% moisture, room temperature	53.84	269	0.00435
82° C	52.14	255	0.00463



(a) Cross-sectional view.



(b) Buffer strip detail.



(c) Plan view.

Figure 1. Buffer strip configuration.

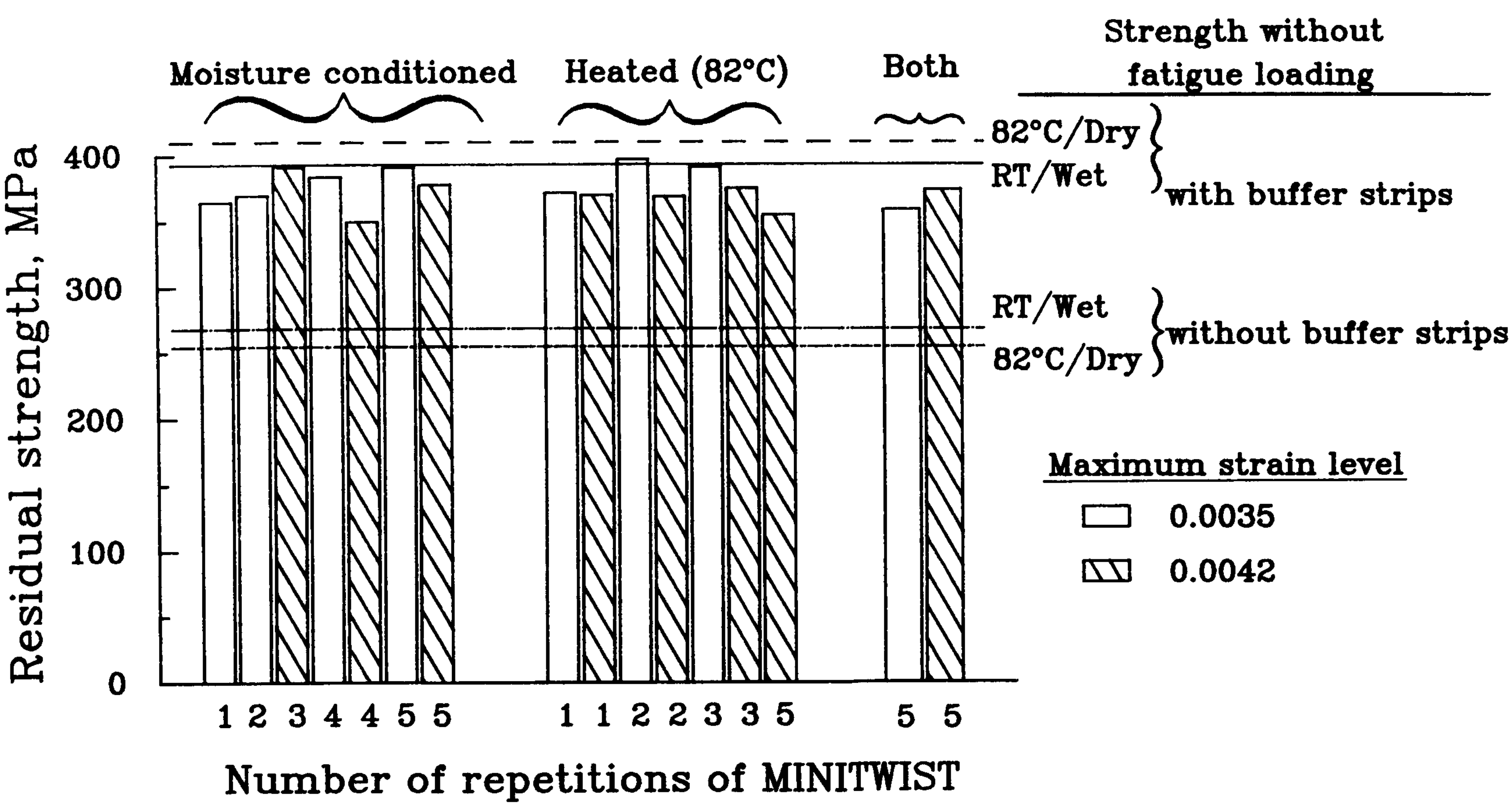


Figure 2. Residual strengths of Kevlar-49 buffer strip panels.

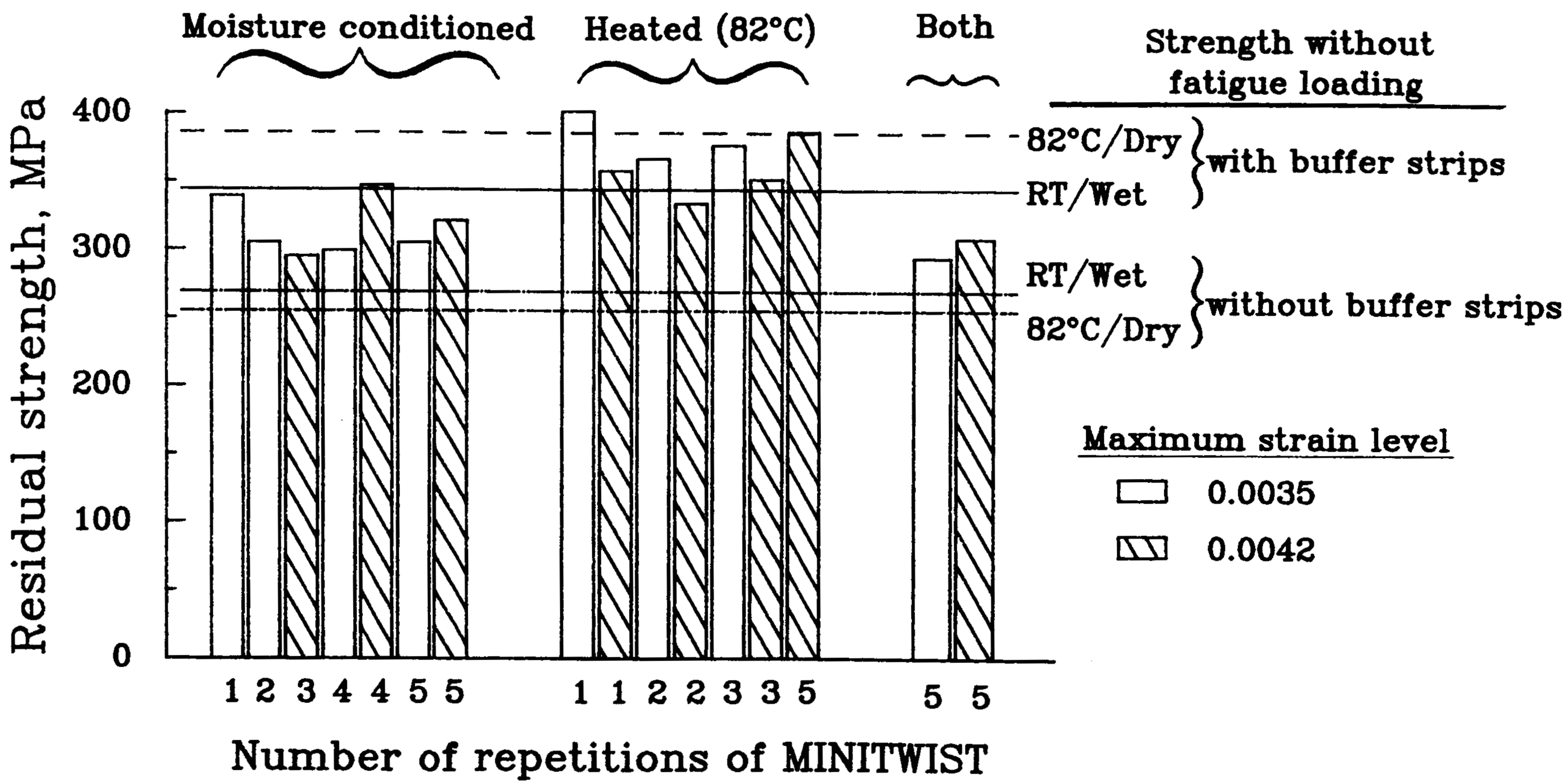


Figure 3. Residual strengths of S-glass buffer strip panels.

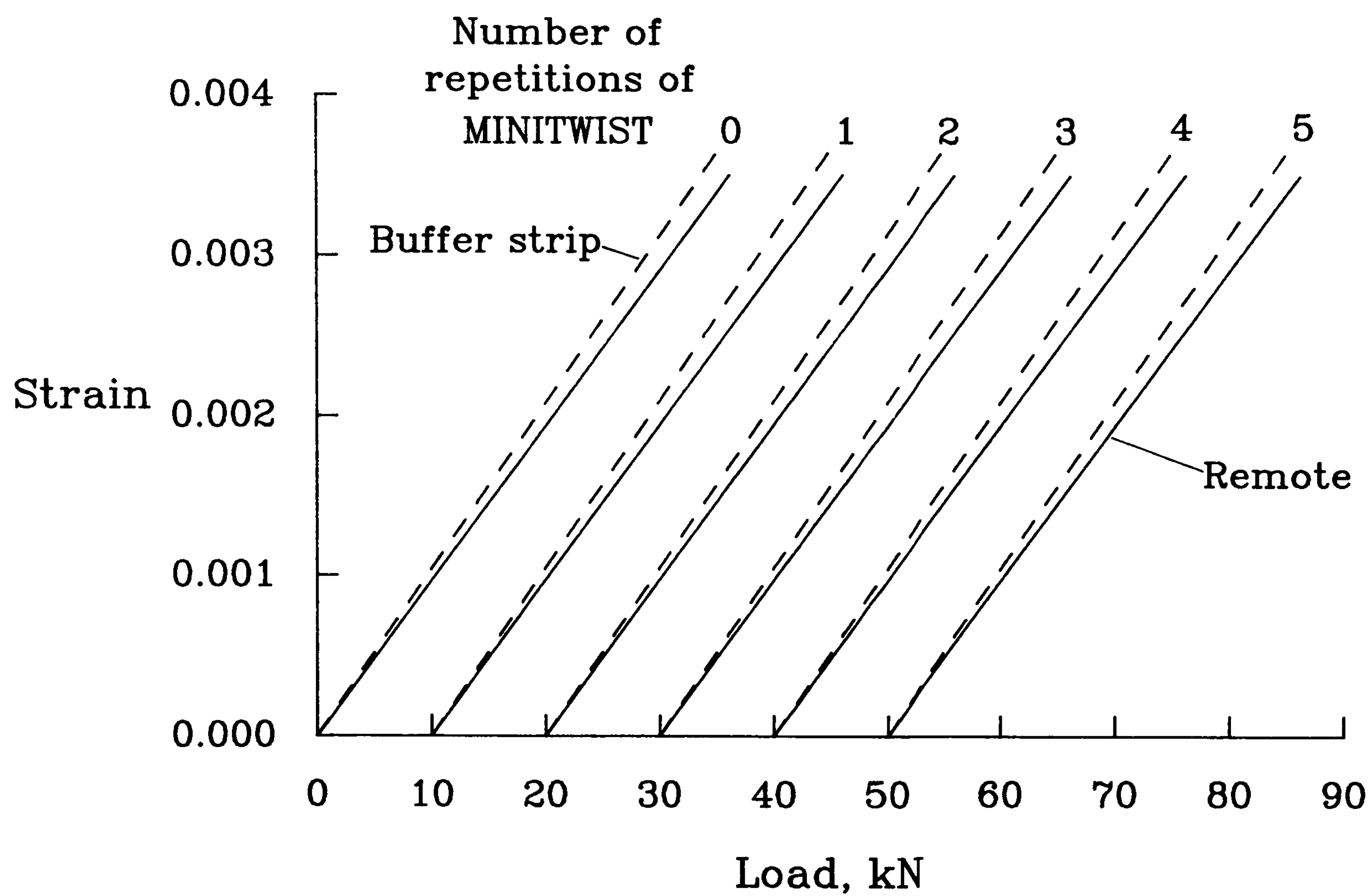


Figure 4. Periodic plots of load versus strain for five repetitions of MINITWIST spectrum. Moisture conditioning. $\epsilon_{max} = 0.0035$.

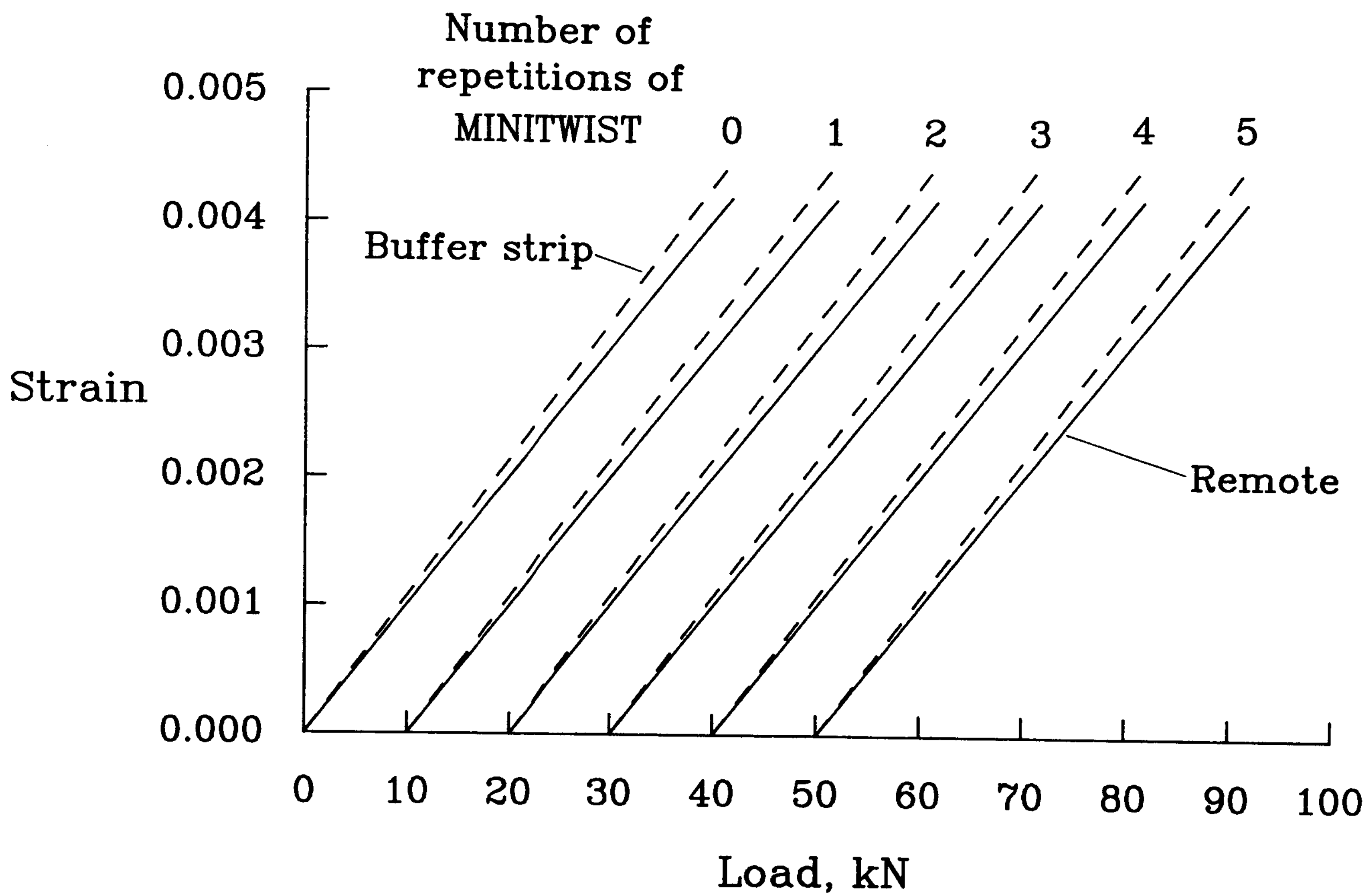


Figure 5. Periodic plots of load versus strain for five repetitions of MINITWIST spectrum. Moisture conditioning. $\epsilon_{max} = 0.0042$.

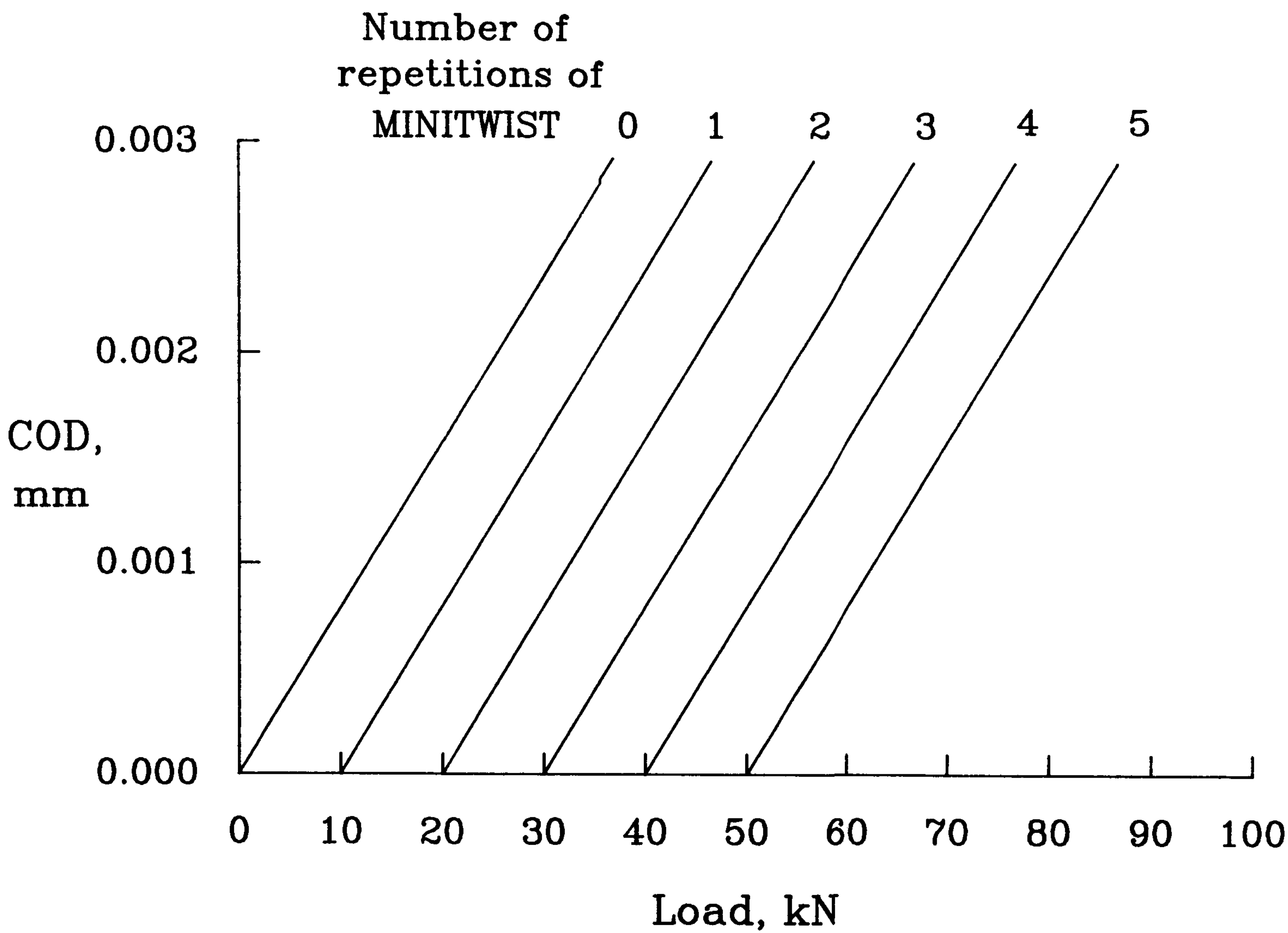


Figure 6. Periodic plots of load versus COD for five repetitions of MINITWIST spectrum. Moisture conditioning. $\epsilon_{max} = 0.0035$.

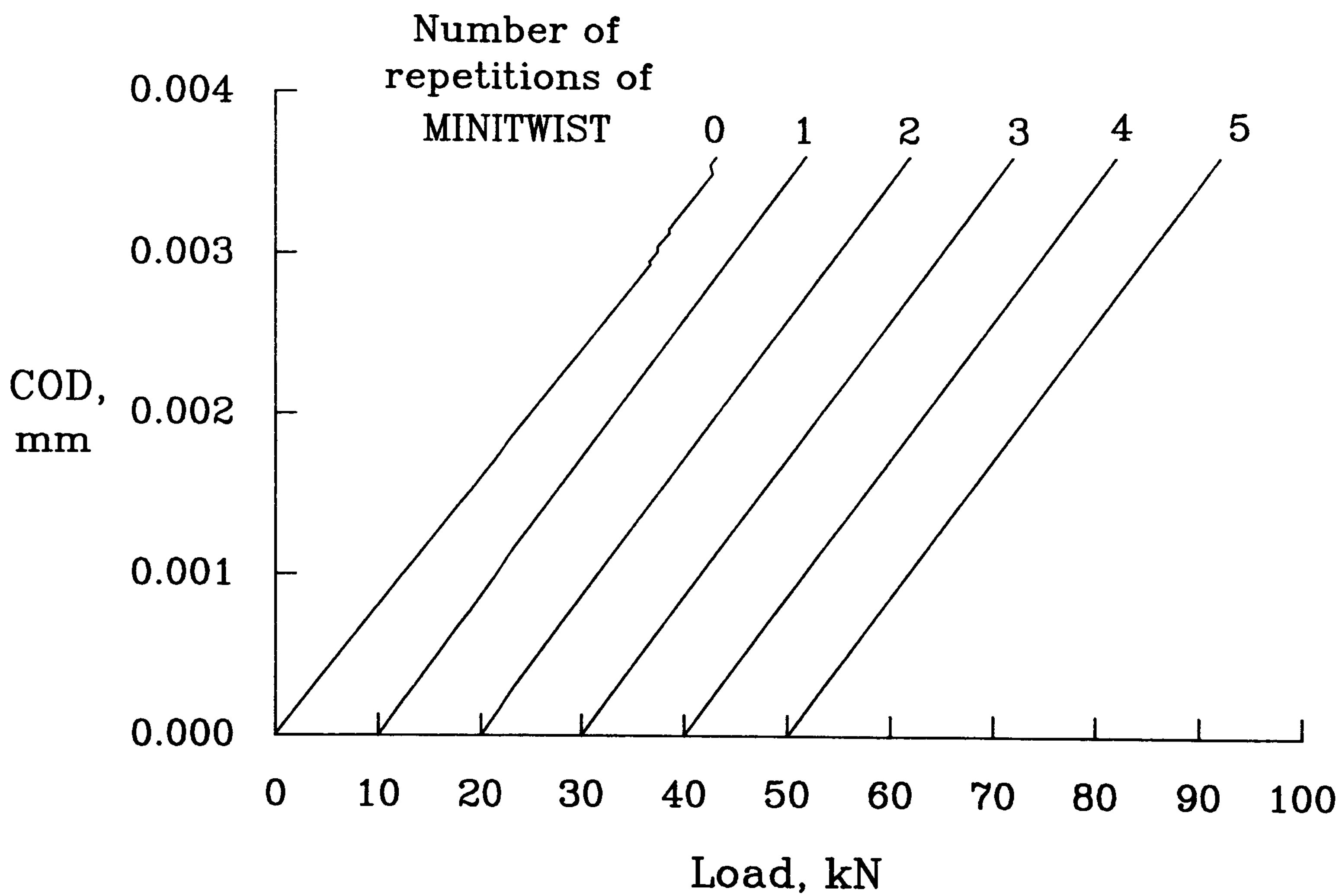


Figure 7. Periodic plots of load versus COD for five repetitions of MINITWIST spectrum. Moisture conditioning. $\epsilon_{max} = 0.0042$.

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15. Supplementary Notes

16. Abstract

The effects of fatigue loading combined with moisture and heat on the behavior of graphite/epoxy panels with either Kevlar-49 or S-glass buffer strips were studied. Buffer strip panels, that had a slit in the center to represent damage, were moisture conditioned or heated, fatigue loaded, and then tested in tension to measure their residual strength. Panels were made with a $[45/0/-45/90]_{2S}$ layup with either Kevlar-49 or S-glass buffer strip material. The buffer strips were parallel to the loading direction and were made by replacing narrow strips of the 0-degree graphite plies with Kevlar-49/epoxy or S-glass/epoxy on a one-for-one basis. The panels were subjected to a fatigue loading spectrum with two levels of maximum strain and five different durations of the fatigue spectrum. One group of panels was preconditioned by soaking in 60° C water to produce a 1% weight gain then tested at room temperature. One group was heated to 82° C during the fatigue loading. Another group was moisture conditioned and then tested at 82° C.

The residual strengths of the buffer strip panels were not significantly affected by the fatigue loading, the number of repetitions of the loading spectrum, or the maximum strain level. The moisture conditioning reduced the residual strengths of the S-glass buffer strip panels by 10 to 15% below the ambient results. The moisture conditioning did not have a significant effect on the Kevlar-49 panels. The heating did not affect the panel strengths of the buffer strip panels for either buffer material.

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