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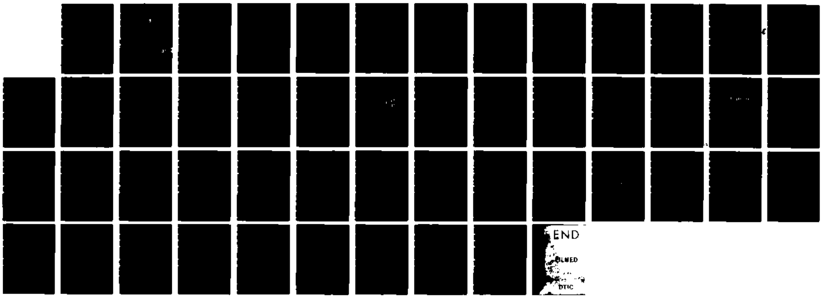

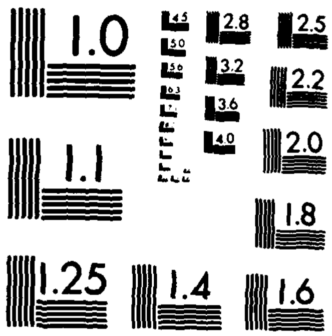

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REPORT NO. NADC-84124-60

AD-A147 352

EVALUATION OF THE ALKALINE PEROXIDE PRE-BOND SURFACE TREATMENT FOR TITANIUM

J. Harper-Tervet and D. H. Neff
LOCKHEED-CALIFORNIA COMPANY
Burbank, CA 91520

OCTOBER 1983

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Alkaline peroxide and Pasajell 107 pre-bond treatments were evaluated with three different adhesives in an effort to increase the durability of bonded titanium structures. Lap shear, wedge and stress durability specimens were prepared and pre-bond surfaces were evaluated after environmental exposures up to six months. Titanium-to-titanium results showed the alkaline peroxide treatment exhibited higher lap shear strengths than the Pasajell 107 treatment at both RT and 180°F. When the adhesives were used without primer, the Pasajell 107 treatment exhibited slightly higher lap shear strengths. The majority of titanium-to-graphite lap shear coupons failed in the composite, confirming the lower interlaminar strength of the composite when compared to the adhesive bonds. Wedge tests were conducted on panels that were cleaned and then stored for 0 month, 3 months and 6 months at elevated temperature and humidity. The alkaline peroxide treated specimens exhibited markedly higher durability than the Pasajell 107 treated specimens. Overall the alkaline peroxide treated specimens demonstrated comparable initial strength to the Pasajell 107 cleaned specimens, but when exposed for various periods of time to elevated temperature and humidity, the alkaline peroxide treated specimens provided a significantly more stable surface and thus a more durable bond.

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SUMMARY

This program was conducted to investigate the performance of a newly developed titanium pre-bond cleaning treatment with three different adhesives. The alkaline peroxide cleaning treatment was developed in an effort to increase the durability of bonded titanium structures. Titanium bonds have historically been shown to be sensitive to severe environmental conditions such as elevated temperature, humidity and stress. A commonly used titanium cleaning treatment, Pasajell 107, was evaluated along with the alkaline peroxide treatment. Lap shear, wedge and stress durability specimens were tested. Environmental exposures up to six months were evaluated.

Alkaline peroxide and Pasajell 107 treated titanium specimens were evaluated with the following combinations of adhesives and primers:

- FM-300 adhesive/no primer
- AF-163 adhesive/no primer
- EA-9654 adhesive/no primer
- FM-300 adhesive/BR-127 primer
- AF-163 adhesive/EC-3960 primer
- EA-9654 adhesive/EA-9228 primer

Titanium-to-titanium lap shear specimens were tested for initial strength at room temperature and at 180°F. Results showed the alkaline peroxide treatment exhibited higher lap shear strengths when tested at both RT and 180°F when the adhesives were used with their respective primers. When the adhesives were used without primer, the Pasajell 107 treatment exhibited slightly higher lap shear strengths.

Titanium-to-graphite lap shear coupons were fabricated to assess the response of the various cleaning treatments and adhesives on these materials. The majority of the coupons failed in the composite, confirming the lower interlaminar strength of the composite when compared to the adhesive bonds.

Wedge tests were conducted on panels that were cleaned and then stored for 0 months, 3 months and 6 months at elevated temperature and humidity. The alkaline peroxide treated specimens exhibited markedly higher durability than the Pasajell 107 treated specimens.

The alkaline peroxide treated specimens demonstrated comparable initial strength to the Pasajell 107 cleaned specimens. When exposed for various periods of time to elevated temperature and humidity, the alkaline peroxide treated specimens provided a significantly more stable surface and thus a more durable bond. The adhesive least affected by variations in cleaning treatments was EA-9654.

BACKGROUND

The use of titanium bonding is widespread throughout the aircraft industry on both military and commercial aircraft. However, full exploitation of adhesively bonded titanium structure has heretofore been hampered by the frequency of titanium disbonds in service and the resulting high maintenance costs.

As a result of the many experimental bonding programs conducted by the Lockheed-California Company, the alkaline peroxide pre-bond cleaning treatment has been identified as providing an extremely stable bonding surface, in addition to being easy to use, non-toxic and non-chromated. The formation of a chemically stable bonding surface makes the alkaline peroxide treatment especially well-suited for numerous military field applications.

The Lockheed-California Company conducted a program sponsored by the Naval Air Development Center to evaluate and compare the alkaline peroxide treatment to a commonly used titanium pre-bond treatment, Pasajell 107. These two treatments were evaluated for initial strength at room temperature and 180°F, strength under sustained load after 0, 3 and 6 month exposure to elevated temperature, and humidity and crack growth after exposure for 0, 3 and 6 months to elevated temperature and humidity. The two cleaning treatments were evaluated on specimens bonded with three different adhesives, each used with and without its respective primer. Surface preparation and cleaning treatment procedures for both the alkaline peroxide treatment and the Pasajell 107 treatment are shown below:

ALKALINE PEROXIDE	PASAJELL 107
1. MEK wipe	1. MEK wipe or equivalent solvent
2. Alkaline clean per Lockheed Process Bulletin PB 79-386	2. Sand surface with 320 grit non-silicone wet or dry abrasive paper.
3. Immersion in a solution of .2M H_2O_2/.5M NaOH at 145°F for 20 minutes	3. Wipe with non-chlorinated solvent until all dust is removed.
4. Rinse for 3 minutes in tap water	4. Apply Pasajell 107 for 12-16 minutes, agitating Pasajell constantly.
5. Rinse for 1 minute in DI water	5. Rinse coated area with distilled or demineralized water to remove Pasajell.
6. Dry in air circulating oven for 30 minutes at 125° - 135°F.	6. Dry at RT or at 150°F with heat lamp.

The adhesives chosen for evaluation on this program were selected after consultation with the Navy. Two 350°F curing and one 250°F curing adhesives were evaluated. The adhesives were used both with and without their respective primers; the various combinations are shown below:

CURE TEMP.	ADHESIVE SYSTEM
250°F	AF-163/no primer (250° cure)
250°F	AF-163/EC-3960 (250° cure)
350°F	FM-300/no primer
350°F	FM-300/BR-127
350°F	EA-9654/no primer
350°F	EA-9654/EA-9228

TEST SPECIMEN FABRICATION AND TEST PROCEDURE

The program was divided into five tasks as shown in the following Tables. Test specimen fabrication and test procedures for each are defined at the end of each table.

TABLE 1. TEST MATRIX FOR Ti-to-Ti LAP SHEAR AND STRESS DURABILITY SPECIMENS (NADC)

ADHESIVE SYSTEM	SURFACE TREATMENT					
	H_2O_2/NaOH			PASAJELL 107		
	RT	180°F	NADC	RT	180°F	NADC
FM-300/BARE	5	5	10	5	5	10
FM-300/BR-127	5	5	10	5	5	10
EA-9654/BARE	5	5	10	5	5	10
EA-9654/EA-9228	5	5	10	5	5	10
AF-163/BARE	5	5	10	5	5	10
AF-163/EC-3960	5	5	10	5	5	10

The titanium-to-titanium lap shear and stress durability coupons were fabricated from bonded panels measuring 8" x 24". Twelve 0.050" thick Ti-6Al-4V sheets were first cleaned with the alkaline peroxide treatment and then bonded with each of three adhesives, with and without primer, resulting in six 8" x 24" bonded panels. Twelve Ti-6Al-4V, Pasajell 107 cleaned sheets were bonded in the same manner. Ten lap shear and ten sustained load stress durability specimens were machined from each bonded panel. The specimen configurations are shown in Figures 1 and 2. Five lap shear specimens were tested at room temperature and five were tested at 180°F. The ten stress durability specimens were forwarded to NADC for sustained load stress durability testing.

The titanium-to-graphite lap shear specimens for testing per Table 2 were fabricated from 0.050" thick Ti-6Al-4V sheet and 24 ply Hercules AS4/3502 composite layed up with the following orientation:

$$(\pm 45,\ 0,\ 90,\ \mp 45,\ 0_2,\ \pm 45,\ 0_2)s.$$

This orientation was selected to produce a graphite laminate possessing comparable modulus (10^7 psi) to the titanium sheet. Eight inch x 12" x 0.12" graphite panels were ultrasonically inspected for voids and were then bonded to the titanium sheets in the same manner as Table 1. Ten lap shear specimens of the configuration shown in Figure 1 were machined from each panel using a special jig manufactured at Lockheed to machine the 1/8" slots in the graphite adherend portion of the specimens. The specimens to be tested at 180°F required a 1/4" diameter hole to be drilled in both ends of the specimen for loading purposes. The drilling of the holes caused minor delamination in the graphite adherends to occur in the hole region. As the delaminations were confined to tab areas it was concluded that the lap shear strength of the test area would not be affected and the specimens were deemed acceptable for testing. Five specimens from each panel were tested at room temperature and five were tested at 180°F.

Titanium-to-titanium wedge test specimens were fabricated for testing as outlined in Table 3. Twelve 6" x 8" x 0.150" bonded panels of the adhesive and cleaning treatment combinations shown in Table 3 were fabricated. Five specimens were machined from each panel and titanium wedges were installed as shown in Figure 2.

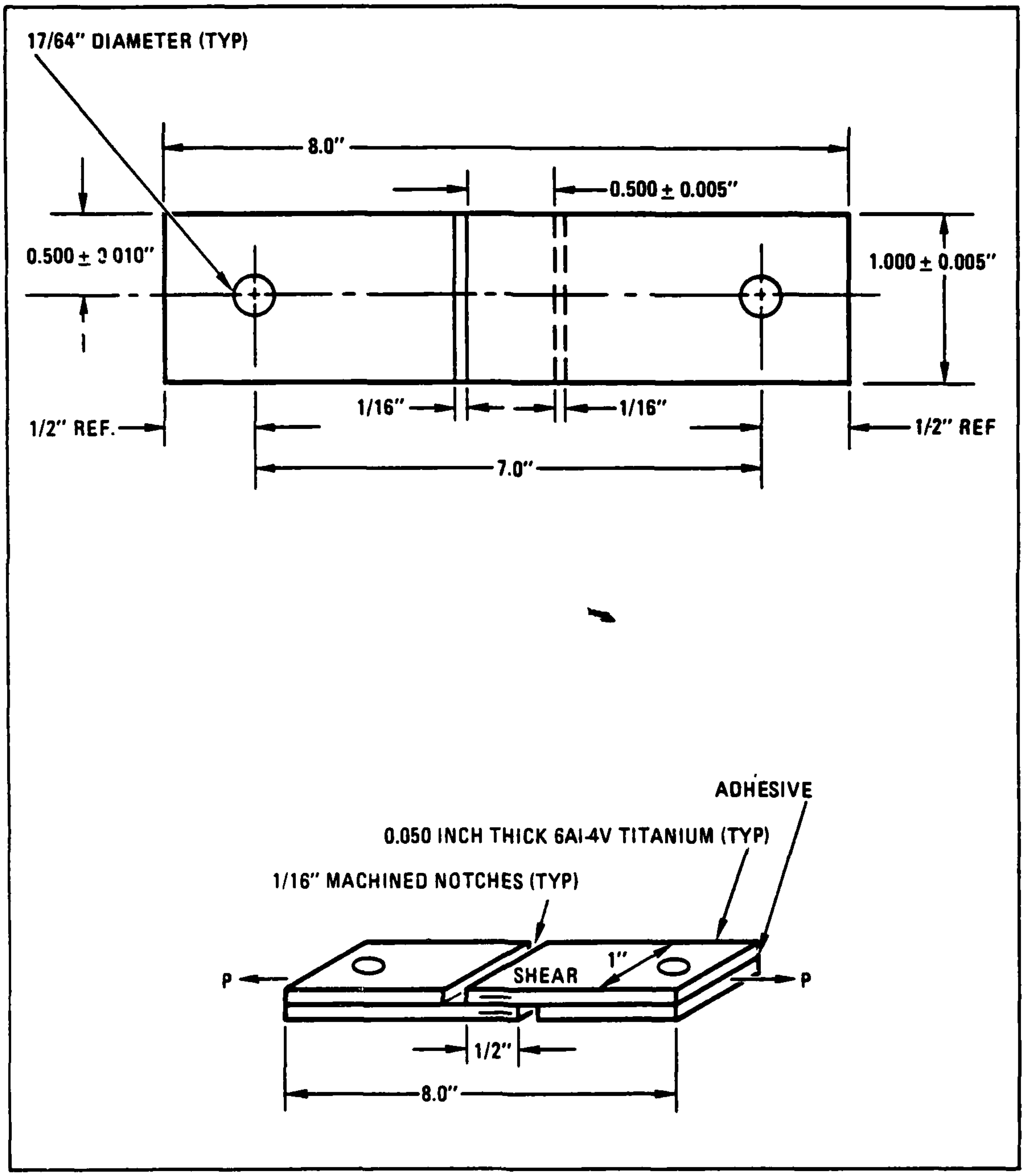

Figure 1. - Lap shear specimen configuration.

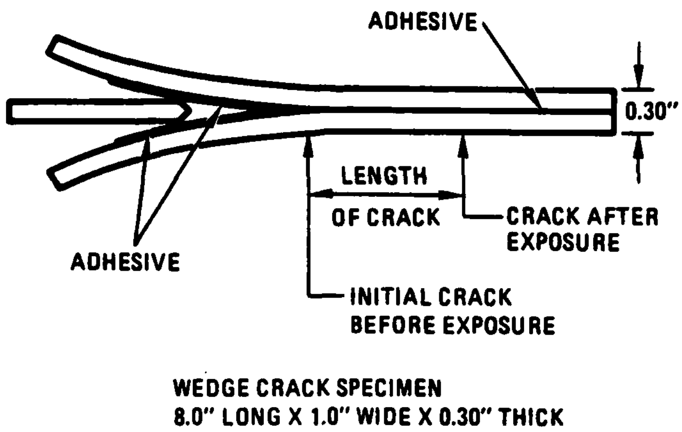

Figure 2. - Wedge test specimen configuration.

TABLE 2. TEST MATRIX FOR Ti-to-Gr LAP SHEARS

ADHESIVE SYSTEM	SURFACE TREATMENT			
	H_2O_2/NaOH		PASAJELL 107	
	RT.	180°F	RT	180°F
FM-300/BARE	5	5	5	5
FM-300/BR-127	5	5	5	5
EA-9654/BARE	5	5	5	5
EA-9654/EA-9228	5	5	5	5
AF-163/BARE	5	5	5	5
AF-163/EC-3960	5	5	5	5

TABLE 3. TEST MATRIX FOR Ti-to-Ti WEDGE TESTS

ADHESIVE SYSTEM	SURFACE TREATMENT	
	H_2O_2/NaOH	PASAJELL 107
FM300/BARE	5	5
FM300/BR-127	5	5
EA-9654/BARE	5	5
EA-9654/EA-9228	5	5
AF-163/BARE	5	5
AF-163/EC-3960	5	5

The resulting crack from wedge installation was measured and the specimens were then installed on racks in a humidity chamber set at 140°F and 100% humidity. The specimens were removed from the chamber and examined for crack growth at intervals of 1 hour, 4 hours, 1 day, 4 days, 7 days, 14 days, and 28 days.

Additional titanium-to-titanium sustained load stress durability coupons were fabricated to assess the effects of out-time storage on the alkaline peroxide and Pasajell 107 treated surfaces for periods of up to six months. Forty-eight 0.050" x 6" x 8" Ti-6Al-4V sheets were surface treated, twenty-four with the alkaline peroxide treatment and twenty-four with the Pasajell 107 treatment. The panels were then installed on racks in a humidity chamber and exposed to 80% relative humidity and room temperature. Following three months exposure, twelve alkaline peroxide and twelve Pasajell 107 treated panels were removed from the humidity chamber and bonded as shown in Table 4. Three specimens were machined from each bonded panel and were sent to NADC for sustained load stress durability testing. Following six months exposure the remaining panels

TABLE 4. TEST MATRIX FOR OUT-TIME SUSTAINED LOAD STRESS DURABILITY TESTS (NADC)

ADHESIVE SYSTEM	SURFACE TREATMENT			
	H_2O_2/NaOH		PASAJELL 107	
	3 MO.	6 MO.	3 MO.	6 MO.
FM-300/BARE	3	3	3	3
FM-300/BR-127	3	3	3	3
EA-9654/BARE	3	3	3	3
EA-9654/EA-9228	3	3	3	3
AF-163/BARE	3	3	3	3
AF-163/EC-3960	3	3	3	3

were removed from the humidity chamber and bonded as shown in Table 4. Autoclave pressure was lost during the cure of the panels bonded with AF-163, resulting in numerous bond-line voids. A decision on whether or not to age and bond new AF-163 specimens was postponed until after the remaining panels were machined. The condition of the machined specimens is described below:

SURFACE TREATMENT	PRIMER	ADHESIVE	CONDITION AFTER MACHINING
Alkaline Peroxide	EA 9228	EA 9654	Acceptable
Alkaline Peroxide	Bare	EA 9654	Acceptable
Alkaline Peroxide	BR-127	FM-300	Acceptable
Alkaline Peroxide	Bare	FM-300	Disbonded
Pasajell 107	BR-127	FM-300	Disbonded
Pasajell 107	EA 9228	EA 9654	Disbonded
Pasajell 107	Bare	EA 9654	Disbonded
Pasajell 107	Bare	FM-300	Not machined due to bonding error

The failure of all Pasajell 107 treated panels during machining led to a decision not to redo the AF-163 bonded panels. The specimens that were successfully machined were sent to NADC for sustained load stress durability testing.

TABLE 5. TEST MATRIX FOR OUT-TIME Ti-to-Ti WEDGE TESTS

ADHESIVE SYSTEM	SURFACE TREATMENT			
	H_2O_2/NaOH		PASAJELL 107	
	3 MO.	6 MO.	3 MO.	6 MO.
FM300/BARE	5	5	5	5
FM300/BR-127	5	5	5	5
EA9654/BARE	5	5	5	5
EA9654/EA9228	5	5	5	5
AF163/BARE	5	5	5	5
AF-163/EC-3960	5	5	5	5

Effects of out-time storage were also evaluated using wedge test specimens as described in Table 5. Prior to bonding, forty-six panels were installed on racks in a humidity chamber along with the specimens from Table 4. Following three months exposure, twenty-four of the panels were removed from the chamber and bonded as shown in Table 5. Five wedge test specimens were machined from each panel and tested as described in Table 3.

The panels remaining in the humidity chamber were removed after six months exposure and bonded as shown in Table 5. As was the case in Table 4, vacuum pressure was lost during the cure cycle of the panels bonded with AF-163. In addition, the panel treated with Pasajell and bonded with FM 300 (without primer) was deleted from six months testing due to poor cleaning procedure.

Specimens from the following seven panels were tested for crack growth after 6 months pre-bond exposure in the humidity chamber.

SURFACE TREATMENT	PRIMER	ADHESIVE
Alkaline Peroxide	EA-9228	EA-9654
Alkaline Peroxide	Bare	EA-9654
Pasajell 107	EA-9228	EA-9654
Pasajell 107	Bare	EA-9654
Alkaline Peroxide	BR-127	FM-300
Alkaline Peroxide	Bare	FM-300
Pasajell 107	BR-127	FM-300

Titanium wedges were inserted in the six month machined specimens and the resulting crack was measured and recorded. The specimens were then installed on racks in a humidity chamber set at 140°F and a relative humidity ranging from 80% to 100%. The crack growth was measured at the same intervals as the 3 month exposure specimens.

TEST RESULTS

Results of the lap shear and wedge tests conducted at the Lockheed-California Company are presented in Tables 6 - 10. Graphical representations of the results are shown in Figures 3 - 13. Results of the sustained load stress durability tests conducted by NADC personnel are not presented in this report.

Results of the titanium-to-titanium lap shears tested at room temperature (Table 6 and Figure 3) show the initial durability provided by the alkaline peroxide treatment to be roughly comparable to that provided by the Pasajell 107 treatment. When the specimens were tested at 180°F, however, the alkaline peroxide treated specimens exhibited a higher lap shear strength when the adhesives were used with a primer. One of the two 350°F curing adhesives, EA-9654, exhibited a very stable bondline, irregardless of the cleaning treatment or primer usage. This insensitivity to adherend preparation is again seen in the wedge test results discussed later in the report.

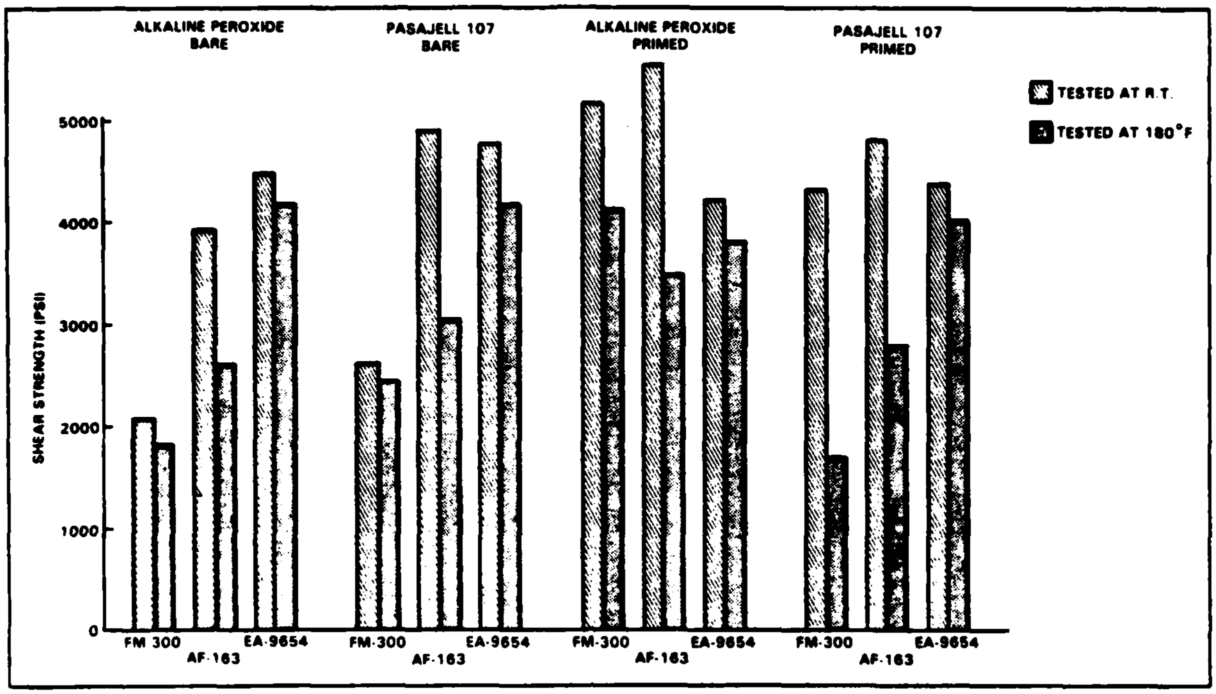

Figure 3. Titanium-to-Titanium Lap Shear Results

The results shown in Table 7 and Figure 4 of the titanium-to-graphite lap shear coupons verify the predicted lower interlaminar strength of graphite composite material when compared to adhesive bonds. The majority of the failure modes consist of delamination of the graphite plies rather than either adhesive or cohesive failure of the bond. There were a small number of partial adhesive and cohesive failures as shown in Table 7, but these were overshadowed by the graphite failures.

Table 8 and Figures 5 - 7 show the results of wedge tests performed on titanium-to-titanium specimens bonded immediately following either the alkaline peroxide or Pasajell 107 treatment. Crack growth measurements over a period of twenty-eight days reveal a significant difference in bond response of alkaline peroxide vs. Pasajell 107 treated specimens, and between primed and unprimed specimens. The alkaline peroxide treated specimens exhibit a much lower amount of crack growth than do the Pasajell 107 treated specimens.

TABLE 6. TITANIUM-to-TITANIUM LAP SHEARS - RESULTS (SHEET 1 OF 5)

Ten coupons were machined from 12 different panels. The coupons are identified as -L through -U in each panel set. Coupons -L through -P were tested at room temperature and -Q through -U at 180°F. The panels are identified as follows:

Panel Number	Surface Treatment	Primer	Adhesive
1	Alkaline Peroxide	BR127	FM300
2	Pasajell 107	BR127	FM300
3	Pasajell 107	bare	FM300
4	Pasajell 107	EA9228	EA9654
5	Pasajell 107	bare	EA9654
6	Alkaline Peroxide	EA9228	EA9654
7	Pasajell 107	EC3960	AF163
8	Alkaline Peroxide	EC3960	AF163
9	Pasajell 107	bare	AF163
10	Alkaline Peroxide	bare	EA9654
11	Alkaline Peroxide	bare	AF163
12	Alkaline Peroxide	bare	FM300

Part A of Table 1 contains the individual and average values for all coupons. Part B of the Table details the failure modes and approximate percentages of each failure mode.

TABLE 6. TITANIUM-to-TITANIUM LAP SHEARS - RESULTS (SHEET 2 OF 5)

PART A

	SPECIMEN IDENTIFICATION	ROOM TEMP		SPECIMEN IDENTIFICATION	180°F	
		IND.	AVG.		IND.	AVG.
		PSI			PSI	
Panel 1	L	4740		Q	4120	
	M	5500		R	4160	
	N	5500	5,190	S	4160	4,150
	O	4950		T	4180	
	P	5260		U	4130	
Panel 2	L	4750		Q	1880	
	M	4100		R	2260	
	N	3480	4,342	S	1420	1,712
	O	4580		T	1420	
	P	4800		U	1580	
Panel 3	L	2440		Q	2420	
	M	2340		R	2440	
	N	4340	2,630	S	2540	2,467
	O	1830		T	Damaged	
	P	2200		U	Damaged	
Panel 4	L	3400		Q	4200	
	M	4860		R	3520	
	N	4560	4,390	S	4020	4,024
	O	4630		T	3940	
	P	4500		U	4440	
Panel 5	L	4570		Q	4300	
	M	4990		R	4360	
	N	4900	4,792	S	4320	4,188
	O	4800		T	4300	
	P	4700		U	3660	
Panel 6	L	4020		Q	4160	
	M	5110		R	3880	
	N	1820	4,230	S	4420	3,816
	O	4950		T	4000	
	P	5250		U	2620	

TABLE 6. TITANIUM-to-TITANIUM LAP SHEARS - RESULTS (SHEET 3 OF 5)

PART A (Continued)

	SPECIMEN IDENTIFICATION	ROOM TEMP. IND.	ROOM TEMP. AVG.	SPECIMEN IDENTIFICATION	180°F IND.	180°F AVG.
		PSI			PSI	
Panel 7	L	5040		Q	3560	
	M	5230		R	3340	
	N	4980	4,830	S	1680	2,800
	O	3500		T	2960	
	P	5400		U	2460	
Panel 8	L	5670		Q	3640	
	M	5690		R	3800	
	N	5450	5,544	S	3740	3,516
	O	5350		T	3620	
	P	5560		U	2780	
Panel 9	L	4000		Q	3340	
	M	4770		R	3100	
	N	5300	4,920	S	3320	3,072
	O	5050		T	2920	
	P	5480		U	2680	
Panel 10	L	5100		Q	4480	
	M	3200		R	4440	
	N	4400	4,500	S	4400	4,188
	O	5050		T	4200	
	P	4750		U	3420	
Panel 11	L	3800		Q	2560	
	M	3260		R	2500	
	N	3420	3,958	S	2600	2,636
	O	4550		T	2820	
	P	4760		U	2700	
Panel 12	L	2750		Q	3260	
	M	1690		R	1760	
	N	1950	2,092	S	3240	1,836
	O	1450		T	Damaged	
	P	2620		U	920	

TABLE 6. TITANIUM-to-TITANIUM LAP SHEARS - RESULTS (SHEET 4 OF 5)

PART B

	SPECIMEN IDENTIFICATION	RT				SPECIMEN IDENTIFICATION	180°F			
		CO%	AM%	AP%	CP%		CO%	AM%	AP%	CP%
Panel 1	L	80		20		Q	100			
	M	80		20		R	100			
	N	40		60		S	100			
	O	30		70		T	100			
	P	30		70		U	100			
Panel 2	L	15	60	25		Q	30	70		
	M		90	10		R		50	50	
	N		95	5		S	10	90		
	O		95	5		T	10	90		
	P	70		30		U	15	85		
Panel 3	L		100			Q		100		
	M		100			R		100		
	N		100			S		100		
	O		100			T		Damaged		
	P		100			U		Damaged		
Panel 4	L	80	10		10	Q				100
	M	5	10		85	R		15		85
	N	5	10		85	S		10		90
	O	10	10		80	T		15		85
	P	5	10		85	U		10		90
Panel 5	L	90	10			Q	50	50		
	M	90	10			R	40	60		
	N	90	10			S	40	60		
	O	90	10			T	40	60		
	P	90	10			U	10	90		
Panel 6	L	70			30	Q	5	95		
	M	60			40	R	30	65		5
	N	60			40	S	35	65		
	O	50			50	T	5	95		
	P	60			40	U	50	50		

Code = CO – Cohesive
CP – Cohesive/Primer
AP – Adhesive/Primer
AM – Adhesive/Metal

TABLE 6. TITANIUM-to-TITANIUM LAP SHEARS - RESULTS (SHEET 5 OF 5)

PART B (Continued)

	SPECIMEN IDENTIFICATION	RT				SPECIMEN IDENTIFICATION	180°F			
		CO%	AM%	AP%	CP%		CO%	AM%	AP%	CP%
Panel 7	L	10	90			Q	15	85		
	M	20	80			R	15	85		
	N	10	90			S	20	80		
	O	10	90			T	65	30	5	
	P	10	90			U	60	15	25	
Panel 8	L	100				Q	100			
	M	100				R	100			
	N	100				S	100			
	O	100				T	100			
	P	100				U	60	10	30	
Panel 9	L	90	10			Q	60	40		
	M	90	10			R	35	65		
	N	90	10			S	40	60		
	O	80	20			T	50	50		
	P	90	10			U	50	50		
Panel 10	L	5	95			Q	65	45		
	M	5	95			R	50	50		
	N		100			S	50	50		
	O	15	85			T	45	55		
	P	20	80			U	5	95		
Panel 11	L	50	50			Q		100		
	M	60	40			R	5	95		
	N	60	40			S	100			
	O	60	40			T	30	70		
	P	60	40			U	5	95		
Panel 12	L		100			Q		100		
	M		100			R		100		
	N		100			S		100		
	O		100			T		Damaged		
	P		100			U	30	70		

Code = CO – Cohesive
CP – Cohesive/Primer
AP – Adhesive/Primer
AM – Adhesive/Metal

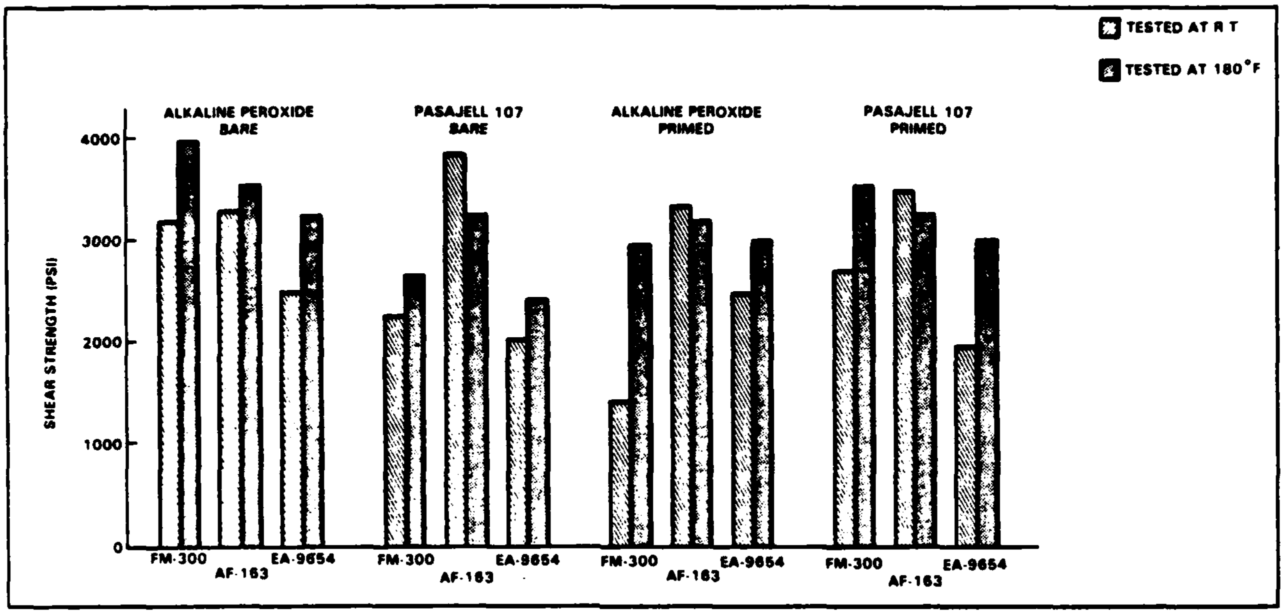

Figure 4. Titanium-to-Graphite Lap Shear Results

The effects of primer usage are seen in Figures 5 - 7 when the crack growth of the primed specimens is compared to the increasing crack growth of the unprimed specimens. The wedge test specimens bonded with EA-9654 show a markedly lower sensitivity to both cleaning treatment and primer vs. no primer selection as seen earlier in the titanium-to-titanium lap shear coupons.

The effects of out-time storage of the surface treated but unbonded specimens can be seen in the results of wedge testing shown in Table 9 and Figures 8 - 10. The improved bond durability provided by the more stable alkaline peroxide treated surface is evident in the crack growth curves.

The alkaline peroxide treated specimens show a distinctly lower amount of crack growth and by the end of the test period the crack growth curves have essentially leveled off. As in the previous wedge tests, the use of primer tends to decrease the amount of crack growth, especially when used on Pasajell 107 treated specimens. The EA-9654 bonded specimens again show a very low sensitivity to both cleaning treatment and primer usage.

TABLE 7. TITANIUM-to-GRAPHITE LAP SHEARS - RESULTS (SHEET 1 OF 5)

Ten coupons were machined from 12 different titanium-to-graphite panels. The coupons are identified as -1 through -10 in each panel set. Coupons -1 through -5 were tested at room temperature and -6 through -10 at 180°F. The panels are identified as follows:

Panel Number	Surface Treatment	Primer	Adhesive
1	Alkaline Peroxide	BR127	FM300
2	Pasajell 107	BR127	FM300
3	Pasajell 107	bare	FM300
4	Pasajell 107	EA9228	EA9654
5	Pasajell 107	bare	EA9654
6	Alkaline Peroxide	EA9228	EA9654
7	Pasajell 107	EC3960	AF163
8	Alkaline Peroxide	EC3960	AF163
9	Pasajell 107	bare	AF163
10	Alkaline Peroxide	bare	EA9654
11	Alkaline Peroxide	bare	AF163
12	Alkaline Peroxide	bare	FM300

Part A of Tables III and IV contains the individual and average values for all coupons. Part B of the Tables details the failure modes and approximate percentages of each failure mode.

TABLE 7. TITANIUM-to-GRAPHITE LAP SHEARS - RESULTS (SHEET 2 OF 5)
PART A

	SPECIMEN IDENTIFICATION	ROOM TEMP.		SPECIMEN IDENTIFICATION	180°F	
		IND.	AVG.		IND.	AVG.
		PSI			PSI	
Panel 1	1	1462		6	2285	
	2	1465		7	2719	
	3	1422	1,410	8	3249	2,969
	4	1404		9	3618	
	5	1295		10	2975	
Panel 2	1	2021		6	4109	
	2	2776		7	3574	
	3	1814	2,718	8	4000	3,561
	4	2924		9	4000	
	5	4054		10	2122	
Panel 3	1	2357		6	2547	
	2	2400		7	3536	
	3	1736	2,221	8	2481	2,662
	4	2639		9	2727	
	5	1971		10	2019	
Panel 4	1	1702		6	2321	
	2	1604		7	3352	
	3	2260	1,975	8	2885	3,015
	4	2368		9	3500	
	5	1942		10	3019	
Panel 5	1	2196		6	2593	
	2	2294		7	2321	
	3	1444	2,019	8	2965	2,419
	4	2132		9	2044	
	5	2028		10	2174	
Panel 6	1	2189		6	3094	
	2	2887		7	3224	
	3	2331	2,516	8	3075	3,014
	4	3104		9	3158	
	5	2067		10	2520	

TABLE 7. TITANIUM-to-GRAPHITE LAP SHEARS - RESULTS (SHEET 3 OF 5)

PART A (Continued)

	SPECIMEN IDENTIFI-CATION	ROOM TEMP.		SPECIMEN IDENTIFI-CATION	180°F	
		IND.	AVG.		IND.	AVG.
		PSI			PSI	
Panel 7	1	3361		6	3278	
	2	3302		7	3300	
	3	3441	3,503	8	3310	3,288
	4	3731		9	3154	
	5	3679		10	3396	
Panel 8	1	4208		6	3423	
	2	4755		7	3421	
	3	3423	3,353	8	3052	3,199
	4	2361		9	3193	
	5	2019		10	2906	
Panel 9	1	3679		6	3265	
	2	3777		7	3328	
	3	4620	3,857	8	3558	3,254
	4	3793		9	3137	
	5	3418		10	2981	
Panel 10	1	2481		6	3542	
	2	2281		7	3268	
	3	2700	2,510	8	3235	3,225
	4	2107		9	3644	
	5	2981		10	2436	
Panel 11	1	3287		6	3175	
	2	3579		7	3720	
	3	3500	3,306	8	3837	3,572
	4	4019		9	3738	
	5	2143		10	3389	
Panel 12	1	3294		6	3904	
	2	2883		7	4000	
	3	3235	3,183	8	4078	3,976
	4	3600		9	4091	
	5	2902		10	3808	

TABLE 7. TITANIUM-to-GRAPHITE LAP SHEARS - RESULTS (SHEET 4 OF 5)

PART B

	SPECIMEN IDENTIFI-CATION	RT				SPECIMEN IDENTIFI-CATION	180°F			
		AG%	GD%	AM%	CO%		AG%	GD%	AM%	CO%
Panel 1	1	50	50			6	50	50		
	2	50	50			7	50	50		
	3		100			8	50	50		
	4	70	30			9	50	50		
	5	50	50			10	100			
Panel 2	1	50	50			6	50	50		
	2	50	50			7	50	50		
	3		100			8		100		
	4		100			9	75	25		
	5		100			10	100			
Panel 3	1	50	50			6	50	50		
	2	50	50			7	50	50		
	3	50	50			8		100		
	4	50	50			9		100		
	5	50	50			10	50	50		
Panel 4	1		100			6	25	75		
	2		100			7	25	75		
	3		100			8		100		
	4		100			9		100		
	5		100			10	50	50		
Panel 5	1	50	50			6		100		
	2	50	50			7		100		
	3		100			8		100		
	4	50	50			9		100		
	5		100			10		100		
Panel 6	1	25	75			6		100		
	2		100			7	50	50		
	3	50	50			8		100		
	4		100			9	50	50		
	5		100			10				100

Code = AG – Adhesive/Graphite
GD – Graphite Delamination
AM – Adhesive/Metal
CO – Cohesive

TABLE 7. TITANIUM-to-GRAPHITE LAP SHEARS - RESULTS (SHEET 5 OF 5)

PART B (Continued)

	SPECIMEN IDENTIFICATION	RT AG%	RT GD%	RT AM%	RT CO%	SPECIMEN IDENTIFICATION	180°F AG%	180°F GD%	180°F AM%	180°F CO%
Panel 7	1		75	25		6		100		
	2		100			7	25	75		
	3		100			8	50	50		
	4	50	50			9	50	50		
	5	50	50			10		100		
Panel 8	1		100			6		100		
	2	25	75			7		100		
	3	25	75			8		100		
	4		100			9	50	50		
	5	50	50			10	75	25		
Panel 9	1	25	75			6		100		
	2	25	75			7		100		
	3	25	75			8		100		
	4		100			9	25	75		
	5		100			10	50	50		
Panel 10	1	50	50			6		100		
	2	50	50			7	50	50		
	3	25	75			8	50	50		
	4	50	50			9	50	50		
	5	50	50			10		10		90
Panel 11	1		100			6		100		
	2		100			7		100		
	3		100			8		100		
	4		100			9		100		
	5		100			10		80		20
Panel 12	1	25	75			6		100		
	2	25	75			7		100		
	3	25	75			8		100		
	4	25	75			9	15	85		
	5	25	75			10	20	80		

Code = AG – Adhesive/Graphite
GD – Graphite Delamination
AM – Adhesive/Metal
CO – Cohesive

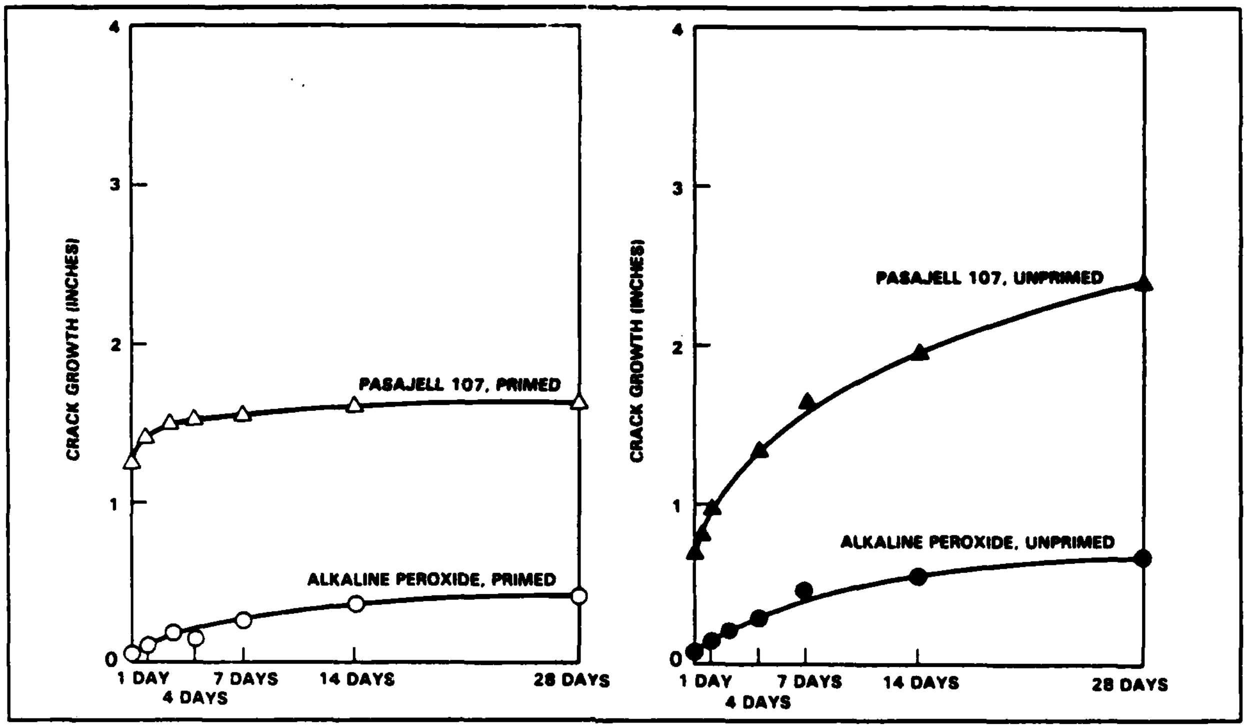

Figure 5. Wedge Test Crack Growth
No Exposure, AF-163

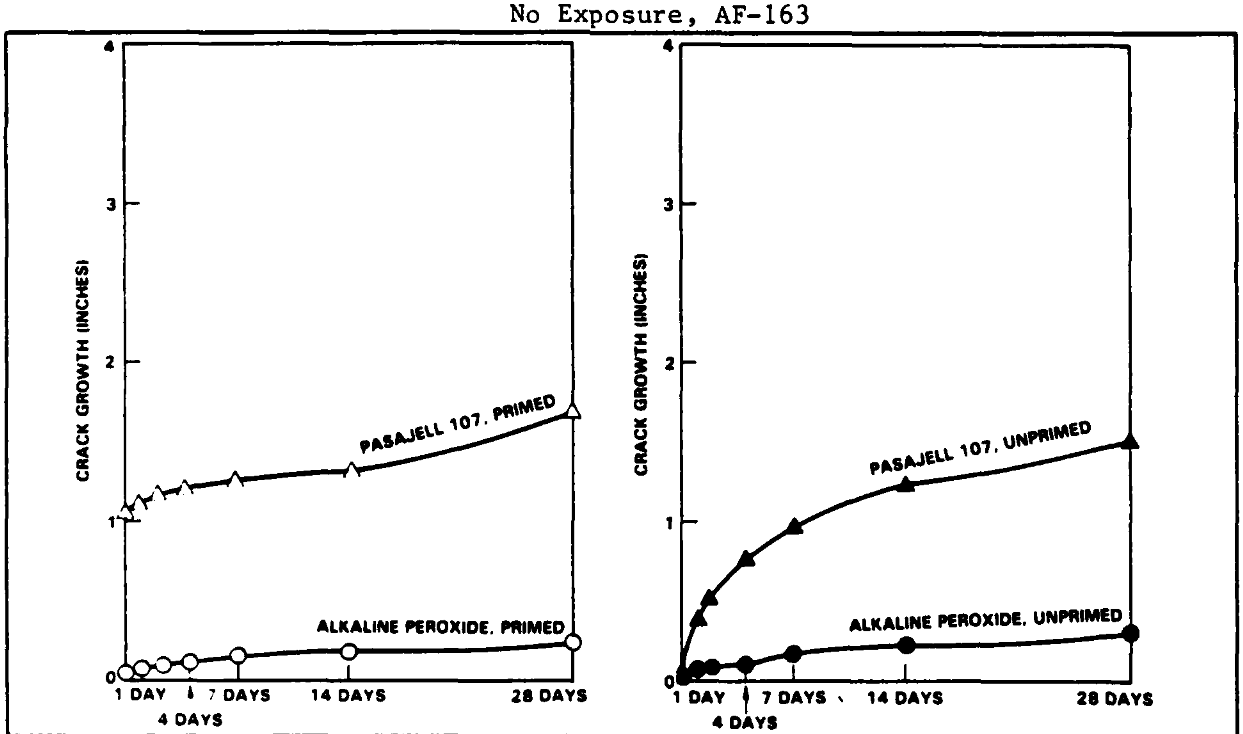

Figure 6. Wedge Test Crack Growth
No Exposure, FM-300

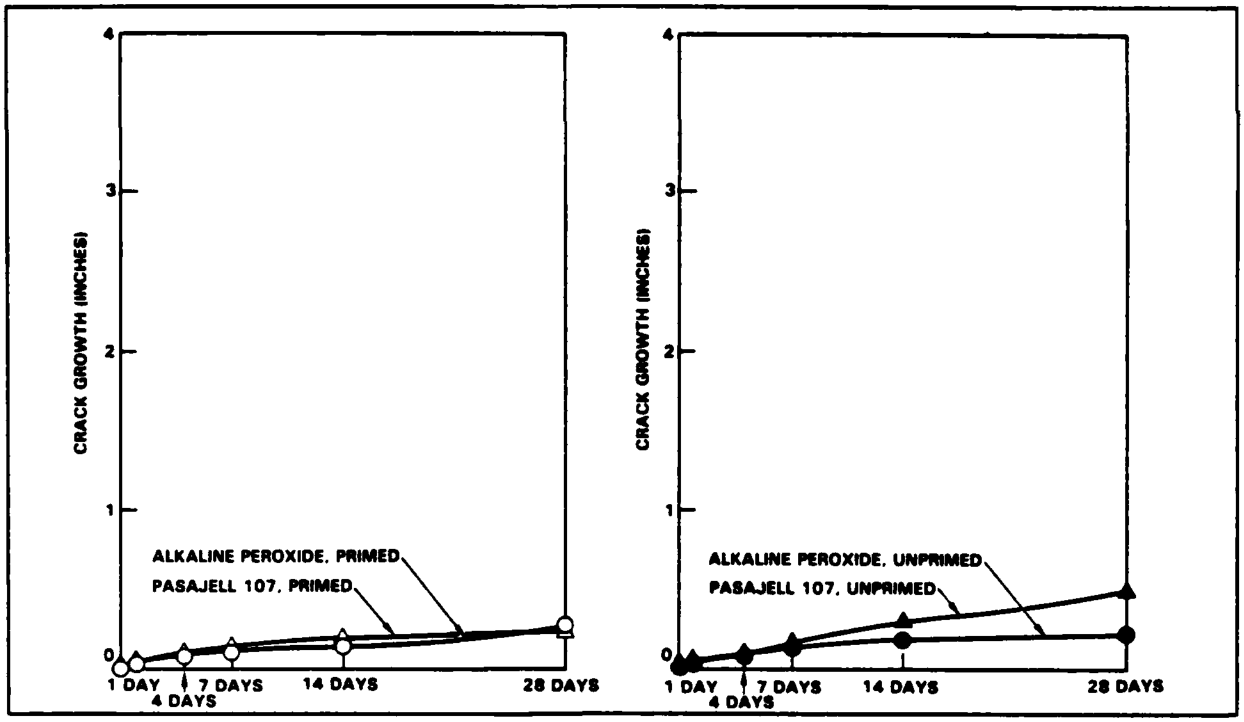

Figure 7. Wedge Test Crack Growth
No Exposure, EA-9654

TABLE 8. TITANIUM-to-TITANIUM WEDGE TESTS - RESULTS (SHEET 1 OF 3)

Twelve panels were fabricated for wedge testing to determine crack growth properties of the cleaning treatments and adhesives. Five specimens were tested from each panel and are labeled 1-5. The panel identification is as follows:

Panel Number	Surface Treatment	Primer	Adhesive
1-0	Pasajell	bare	FM300
2-0	Pasajell	bare	AF163
3-0	Pasajell	bare	EA9654
4-0	Pasajell	BR127	FM300
5-0	Pasajell	EC3960	AF163
6-0	Pasajell	EA9228	EA9654
7-0	Alkaline Peroxide	bare	FM300
8-0	Alkaline Peroxide	bare	AF163
9-0	Alkaline Peroxide	bare	EA9654
10-0	Alkaline Peroxide	BR127	FM300
11-0	Alkaline Peroxide	EC3960	AF163
12-0	Alkaline Peroxide	EA9228	EA9654

The wedge tests were performed under the following conditions:

1 $140^{\circ}F \pm 3^{\circ}F$

2 95-100% relative humidity

3 Crack growth measured at 1 hour, 4 hours, 1 day, 4 days, 7 days, 14 days and 28 days.

4 In the event of total failure of a specimen, it was removed at that time from the humidity chamber.

TABLE 8. TITANIUM-to-TITANIUM WEDGE TESTS - RESULTS (SHEET 2 OF 3)

CRACK LENGTH, inches								
Specimen	Initial Length	After 1 hour	After 4 hours	After 1 day	After 4 days	After 7 days	After 14 days	After 28 days
GROUP 1 – 0								
1	3.42	3.59	3.60	3.72	4.21	4.36	4.54	4.83
2	3.06	3.15	3.18	3.40	3.65	4.07	4.43	4.70
3	3.06	3.10	3.12	3.26	3.71	3.92	4.11	4.35
4	3.12	3.18	3.19	3.36	3.68	3.92	4.23	4.41
5	3.09	3.16	3.55	4.09	4.29	4.44	4.59	5.05
GROUP 2 – 0								
1	1.82	2.54	2.59	2.98	3.43	3.56	3.87	4.43
2	1.87	2.60	2.69	2.85	3.13	3.54	3.96	4.33
3	1.89	2.59	2.61	2.83	3.18	3.43	3.75	4.11
4	1.83	2.65	2.72	2.93	3.34	3.64	4.00	4.39
5	2.21	2.58	2.68	3.07	3.35	3.77	3.91	4.46
GROUP 3 – 0								
1	2.66	2.68	2.71	2.73	2.74	2.84	2.99	3.20
2	2.73	2.74	2.76	2.77	2.78	2.87	2.94	3.15
3	2.63	2.65	2.66	2.67	2.70	2.78	2.92	3.01
4	2.74	2.77	2.79	2.80	2.81	2.83	3.03	3.26
5	2.80	2.82	2.83	2.84	2.86	3.07	3.16	3.37
GROUP 4 – 0								
1	5.90	5.95	5.99	*	*	*	*	*
2	4.21	5.69	5.76	5.78	5.87	6.18	*	*
3	4.33	6.11	6.15	6.18	6.22	6.25	6.28	6.54
4	4.15	5.50	5.51	5.52	5.55	5.58	5.63	5.75
5	3.91	3.98	3.99	4.02	4.25	4.27	4.40	5.09
GROUP 5 – 0								
1	3.18	4.69	4.74	4.80	4.90	4.94	4.96	4.98
2	3.01	3.55	3.64	3.72	3.83	3.91	3.95	4.05
3	3.07	3.95	4.00	4.09	4.13	4.16	4.18	4.23
4	1.85	3.60	3.72	3.80	3.85	3.89	3.94	3.97
5	1.84	3.31	3.56	3.63	3.85	3.91	3.94	3.96
GROUP 6 – 0								
1	2.62	2.63	2.67	2.70	2.73	2.76	2.81	3.02
2	2.69	2.71	2.72	2.72	2.74	2.76	2.78	2.82
3	2.57	2.58	2.60	2.62	2.68	2.70	2.72	2.76
4	2.77	2.78	2.81	2.83	2.85	2.87	2.90	3.03
5	2.20	2.21	2.22	2.23	2.26	2.35	2.39	2.51

*The crack had propagated the full length of the specimen.

TABLE 8. TITANIUM-to-TITANIUM WEDGE TESTS - RESULTS (SHEET 3 OF 3)

	CRACK LENGTH, inches							
Specimen	Initial Length	After 1 hour	After 4 hours	After 1 day	After 4 days	After 7 days	After 14 days	After 28 days
GROUP 7 – 0								
1	2.84	2.85	2.89	2.92	2.97	3.12	3.16	3.20
2	2.67	2.75	2.76	2.79	2.82	2.93	2.97	3.01
3	2.39	2.40	2.41	2.45	2.48	2.49	2.52	2.65
4	3.36	3.39	3.41	3.43	3.45	3.47	3.50	3.59
5	3.13	3.14	3.16	3.17	3.18	3.24	3.38	3.42
GROUP 8 – 0								
1	1.85	1.94	1.95	2.09	2.22	2.31	2.49	2.56
2	1.78	1.82	1.84	1.92	2.04	2.18	2.24	2.33
3	1.80	1.87	1.91	1.94	2.03	2.23	2.36	2.46
4	1.82	1.84	1.88	1.95	2.08	2.31	2.41	2.53
5	1.84	1.89	1.92	2.00	2.15	2.34	2.46	2.61
GROUP 9 – 0								
1	2.67	2.76	2.77	2.79	2.83	2.85	2.91	2.96
2	2.72	2.74	2.76	2.77	2.79	2.85	2.89	2.92
3	2.75	2.77	2.78	2.79	2.80	2.82	2.94	2.99
4	2.67	2.69	2.71	2.73	2.74	2.77	2.79	2.82
5	2.67	2.70	2.72	2.75	2.77	2.84	2.85	2.93
GROUP 10 – 0								
1	2.49	2.53	2.54	2.55	2.58	2.61	2.64	2.70
2	2.36	2.38	2.41	2.44	2.51	2.54	2.58	2.60
3	2.30	2.32	2.35	2.37	2.40	2.44	2.48	2.51
4	2.31	2.35	2.37	2.38	2.39	2.41	2.44	2.47
5	2.38	2.42	2.44	2.47	2.53	2.56	2.61	2.63
GROUP 11 – 0								
1	1.89	1.91	1.92	1.99	2.08	2.16	2.22	2.32
2	1.82	1.85	1.86	1.90	1.93	2.12	2.16	2.24
3	1.86	1.92	1.96	1.99	2.02	2.10	2.22	2.33
4	1.83	1.90	1.91	1.97	2.02	2.11	2.24	2.32
5	1.97	2.01	2.02	2.05	2.09	2.25	2.32	2.39
GROUP 12 – 0								
1	2.68	2.72	2.77	2.78	2.90	2.91	2.94	2.98
2	2.49	2.51	2.52	2.53	2.58	2.61	2.71	2.78
3	2.54	2.57	2.58	2.59	2.60	2.62	2.70	2.74
4	2.59	2.62	2.63	2.64	2.65	2.72	2.75	2.77
5	2.68	2.70	2.71	2.74	2.78	2.84	2.87	2.90

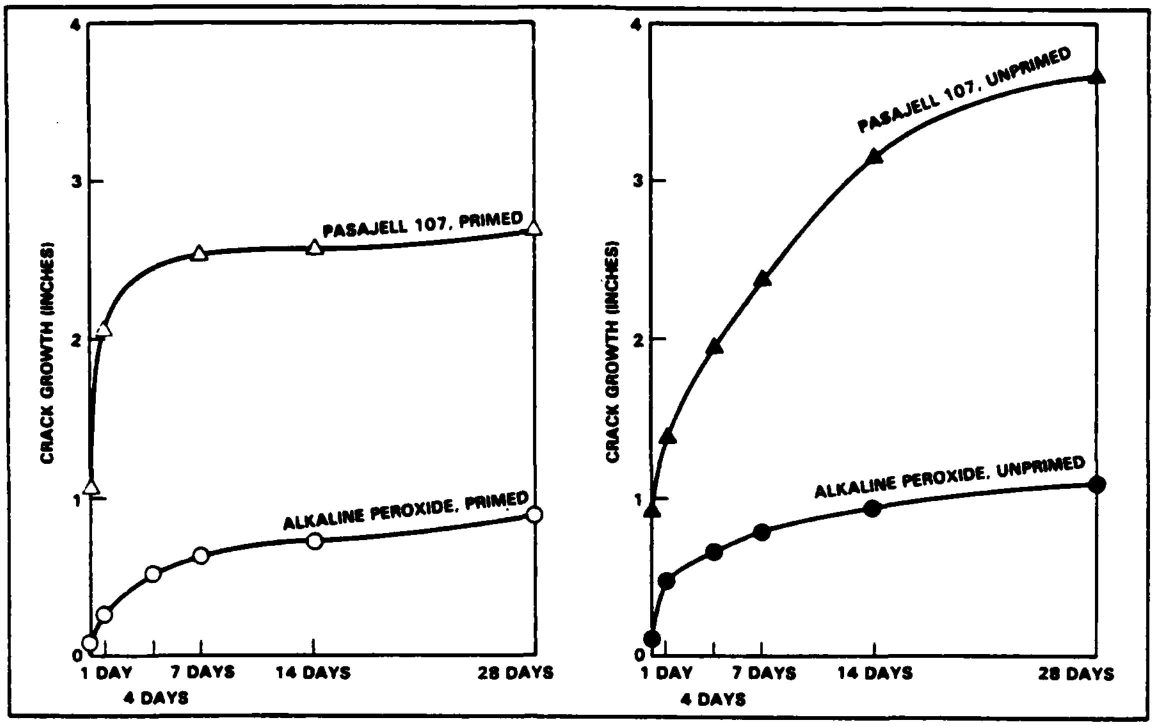

Figure 8. Wedge Test Crack Growth
3 Month Exposure, AF-163

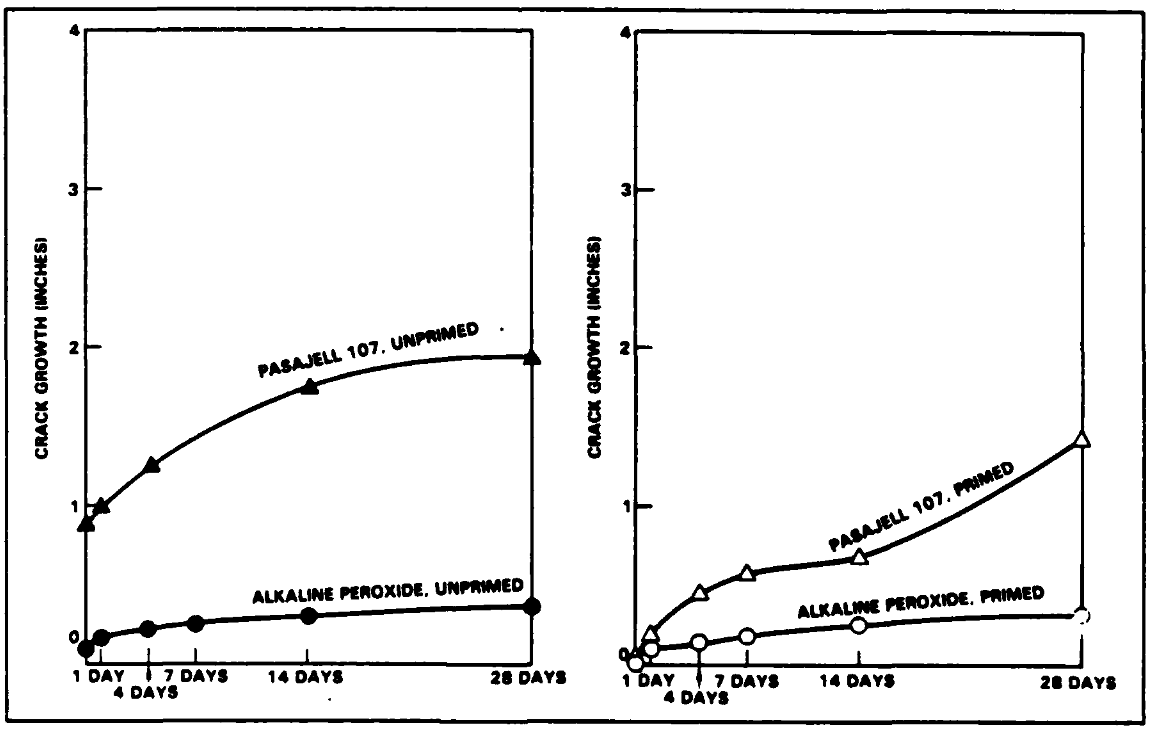

Figure 9. Wedge Test Crack Growth
3 Month Exposure, FM-300

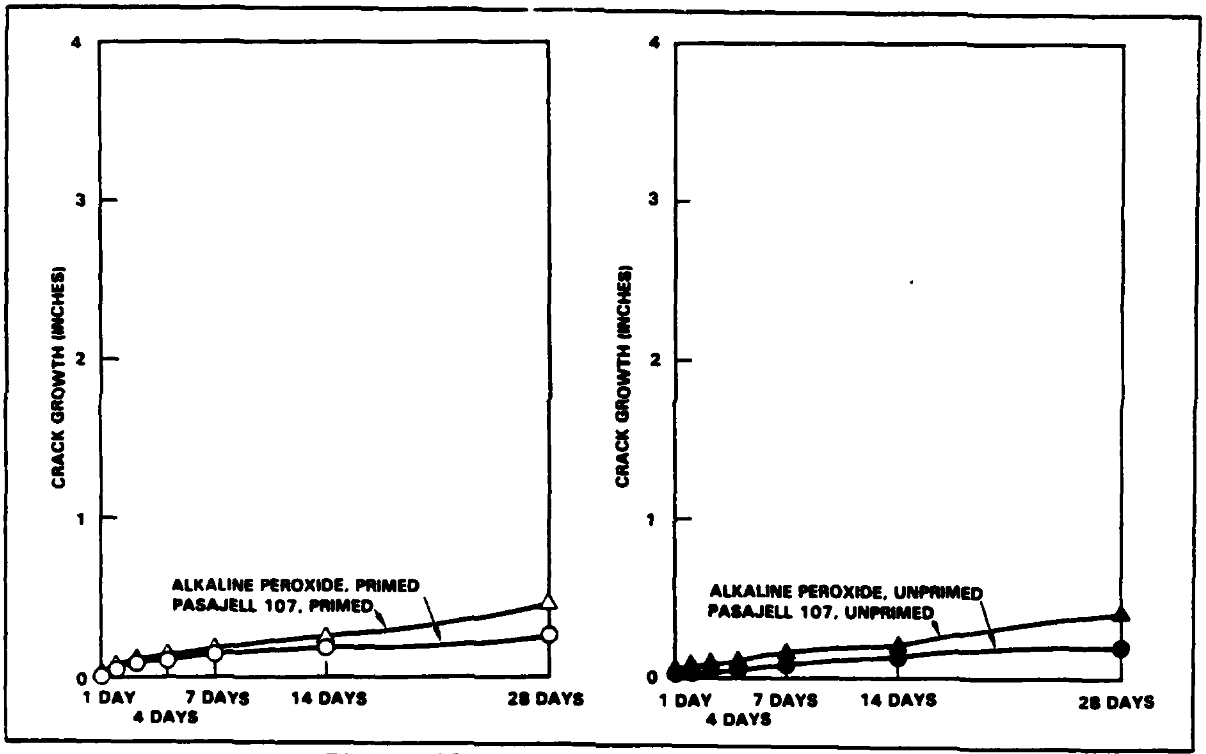

Figure 10. Wedge Test Crack Growth
3 Month Exposure, EA-9654

TABLE 9. TITANIUM-to-TITANIUM WEDGE TESTS (3 MONTH OUT-TIME) - RESULTS (SHEET 1 OF 3)

Twelve panels were fabricated after the Pasajell or Alkaline Peroxide treated titanium sheets were exposed for three months to 80°F and 80% relative humidity. Five coupons were tested from each panel and are identified as 1-5. The panel identification is as follows:

Panel Number	Surface Treatment	Primer	Adhesive
1-30	Pasajell	bare	FM300
2-30	Pasajell	bare	AF163
3-30	Pasajell	bare	EA9654
4-30	Pasajell	BR127	FM300
5-30	Pasajell	EC3960	AF163
6-30	Pasajell	EA9228	EA9654
7-30	Alkaline Peroxide	bare	FM300
8-30	Alkaline Peroxide	bare	AF163
9-30	Alkaline Peroxide	bare	EA9654
10-30	Alkaline Peroxide	BR127	FM300
11-30	Alkaline Peroxide	EC3960	AF163
12-30	Alkaline Peroxide	EA9228	EA9654

Test conditions are per Table 8.

TABLE 9. TITANIUM-to-TITANIUM WEDGE TESTS (3 MONTH OUT-TIME) - RESULTS (SHEET 2 OF 3)

	CRACK LENGTH, inches							
Specimen	Initial Length	After 1 hour	After 4 hours	After 1 day	After 4 days	After 7 days	After 14 days	After 28 days
GROUP 1 – 30								
1	3.91	4.01	4.07	4.23	4.52	4.92	4.96	*
2	5.02	*	*	*	*	*	*	*
3	2.98	3.18	3.43	3.88	5.38	5.44	5.58	*
4	2.99	4.10	4.32	4.42	4.67	4.72	5.12	5.31
5	3.86	3.98	4.33	4.45	4.66	4.99	5.24	5.44
GROUP 2 – 30								
1	1.91	2.88	3.03	3.42	4.20	4.70	5.38	6.16
2	1.91	2.82	2.90	3.33	4.00	4.34	5.09	5.19
3	1.87	2.84	2.96	3.38	3.97	4.33	4.96	5.15
4	1.93	2.85	2.92	3.21	3.72	4.01	4.70	5.41
5	1.98	2.77	2.80	3.10	3.51	4.23	5.30	5.98
GROUP 3 – 30								
1	2.55	2.58	2.60	2.63	2.65	2.83	2.93	3.03
2	2.45	2.47	2.50	2.52	2.54	2.57	2.61	2.88
3	2.37	2.39	2.40	2.43	2.48	2.54	2.57	2.76
4	2.48	2.53	2.54	2.55	2.57	2.60	2.61	2.80
5	2.48	2.54	2.55	2.56	2.58	2.64	2.66	2.95
GROUP 4 – 30								
1	2.48	2.49	2.53	2.69	3.08	3.24	3.40	3.71
2	3.48	3.59	3.60	3.65	3.72	3.90	3.94	4.15
3	3.95	4.03	4.07	4.13	4.33	4.35	4.37	6.72
4	3.54	3.60	3.61	3.63	3.79	3.91	4.02	4.37
5	1.96	2.08	2.09	2.34	2.72	2.91	3.13	3.63
GROUP 5 – 30								
1	2.90	3.92	4.23	4.61	5.16	5.22	5.26	5.31
2	2.83	3.31	3.40	4.66	5.26	5.35	5.38	5.42
3	2.96	3.84	3.89	4.96	5.21	5.25	5.31	5.38
4	3.15	3.66	3.70	5.24	5.45	5.56	5.58	5.68
5	2.96	5.38	5.44	5.54	6.01	6.09	6.12	6.42
GROUP 6 – 30								
1	2.41	2.44	2.51	2.57	2.67	2.68	2.70	3.01
2	2.34	2.35	2.38	2.41	2.47	2.51	2.66	2.85
3	2.47	2.48	2.49	2.53	2.55	2.58	2.71	2.95
4	2.40	2.42	2.44	2.49	2.54	2.55	2.64	2.88
5	2.50	2.54	2.55	2.56	2.58	2.61	2.69	2.71

*The crack had propagated the full length of the specimen.

TABLE 9. TITANIUM-to-TITANIUM WEDGE TESTS (3 MONTH EXPOSURE) - RESULTS (SHEET ⟩ OF 3)

	CRACK LENGTH, inches							
Specimen	Initial Length	After 1 hour	After 4 hours	After 1 day	After 4 days	After 7 days	After 14 days	After 28 days
GROUP 7 – 30								
1	4.77	5.04	5.07	5.14	5.21	5.38	5.42	5.46
2	4.32	4.36	4.40	4.45	4.49	4.50	4.54	4.56
3	4.15	4.16	4.17	4.21	4.25	4.27	4.29	4.40
4	4.45	4.47	4.48	4.56	4.58	4.62	4.66	4.76
5	3.56	3.60	3.65	3.67	3.71	3.75	3.78	3.81
GROUP 8 – 30								
1	2.35	2.42	2.44	2.93	3.25	3.34	3.50	3.71
2	2.35	2.47	2.57	2.69	2.77	2.92	3.14	3.28
3	2.19	2.31	2.43	2.51	2.70	2.87	2.97	3.13
4	2.21	2.34	2.39	2.79	2.91	3.04	3.11	3.38
5	2.29	2.43	2.50	2.87	2.99	3.24	3.31	3.46
GROUP 9 – 30								
1	2.78	2.80	2.81	2.82	2.84	2.86	2.90	2.98
2	2.63	2.64	2.65	2.67	2.71	2.77	2.80	2.84
3	2.72	2.73	2.74	2.77	2.79	2.82	2.87	2.92
4	2.73	2.74	2.74	2.77	2.80	2.84	2.88	2.94
5	2.13	2.14	2.15	2.16	2.17	2.20	2.25	2.27
GROUP 10 – 30								
1	2.52	2.55	2.61	2.62	2.63	2.81	2.84	2.94
2	2.39	2.40	2.42	2.47	2.51	2.56	2.70	2.82
3	2.28	2.32	2.37	2.39	2.40	2.43	2.51	2.56
4	2.37	2.40	2.45	2.46	2.47	2.50	2.52	2.55
5	2.39	2.41	2.44	2.50	2.53	2.59	2.62	2.71
GROUP 11 – 30								
1	2.04	2.09	2.12	2.21	2.51	2.57	2.61	2.70
2	1.95	2.00	2.04	2.18	2.38	2.51	2.64	2.72
3	1.82	1.91	1.98	2.19	2.41	2.51	2.58	2.70
4	1.91	2.02	2.09	2.35	2.55	2.64	2.69	2.97
5	2.06	2.12	2.19	2.25	2.53	2.76	2.92	3.15
GROUP 12 – 30								
1	2.63	2.64	2.71	2.83	2.92	2.96	2.99	3.02
2	2.59	2.62	2.64	2.66	2.67	2.68	2.69	2.80
3	2.62	2.65	2.67	2.69	2.71	2.76	2.78	2.80
4	2.08	2.09	2.10	2.10	2.16	2.22	2.24	2.29
5	2.77	2.78	2.80	2.81	2.85	2.89	2.95	2.99

The results of the wedge test specimens stored for six months under the same conditions as the three month specimens are shown in Table 10 and Figures 11 - 13. The significantly lower amounts of crack growth seen in these specimens is due to the specimen exposure to 80% relative humidity rather than 100% relative humidity. As seen earlier, the EA-9654 bonded specimens show little, if any, sensitivity to cleaning treatment and primer usage.

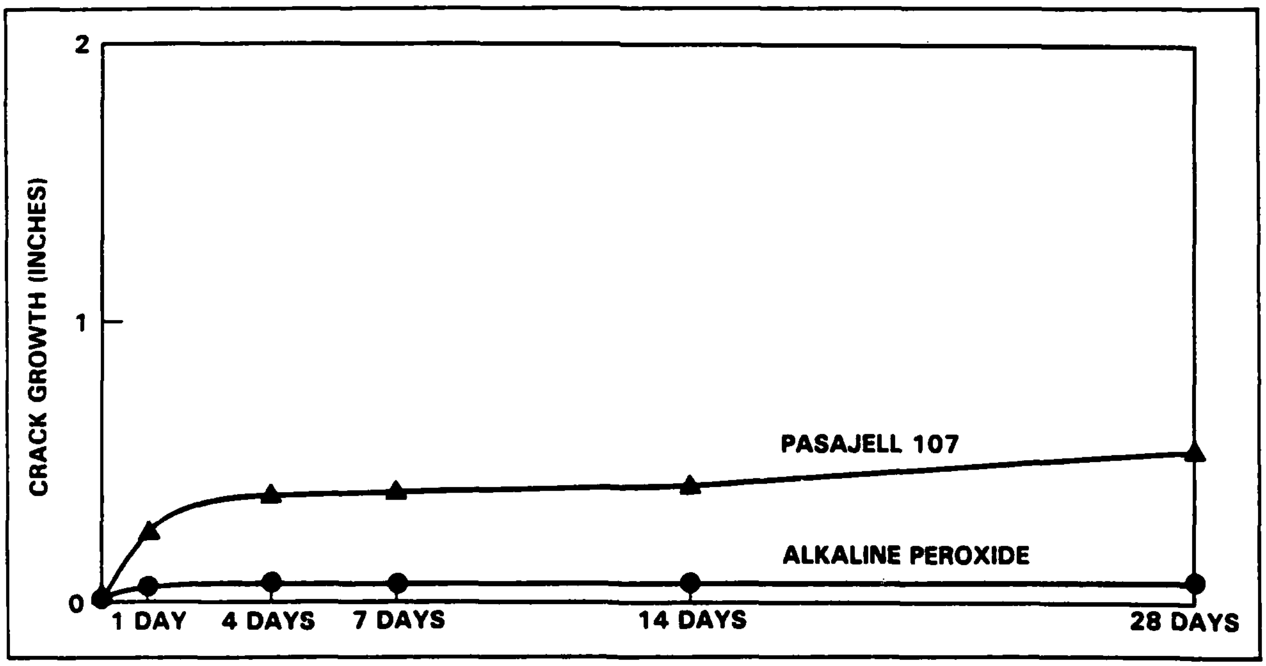

Figure 11. Wedge Test Crack Growth
6 Month Exposure, FM-300, Primed

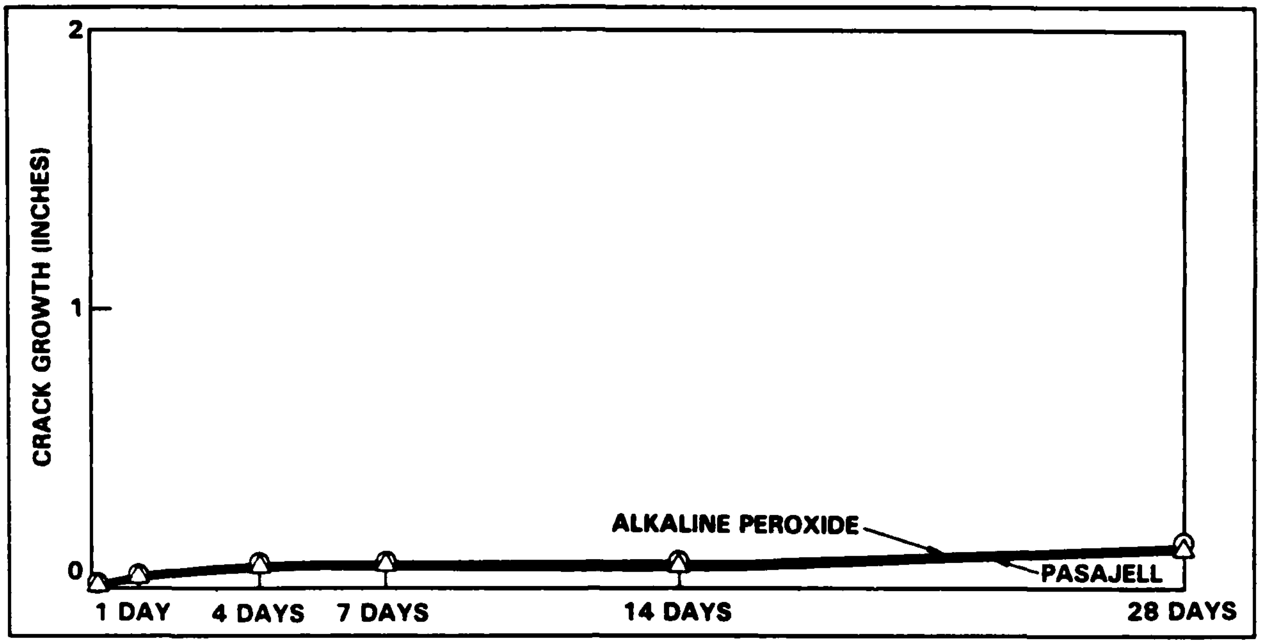

Figure 12. Wedge Test Crack Growth
6 Month Exposure, EA-9654, Unprimed

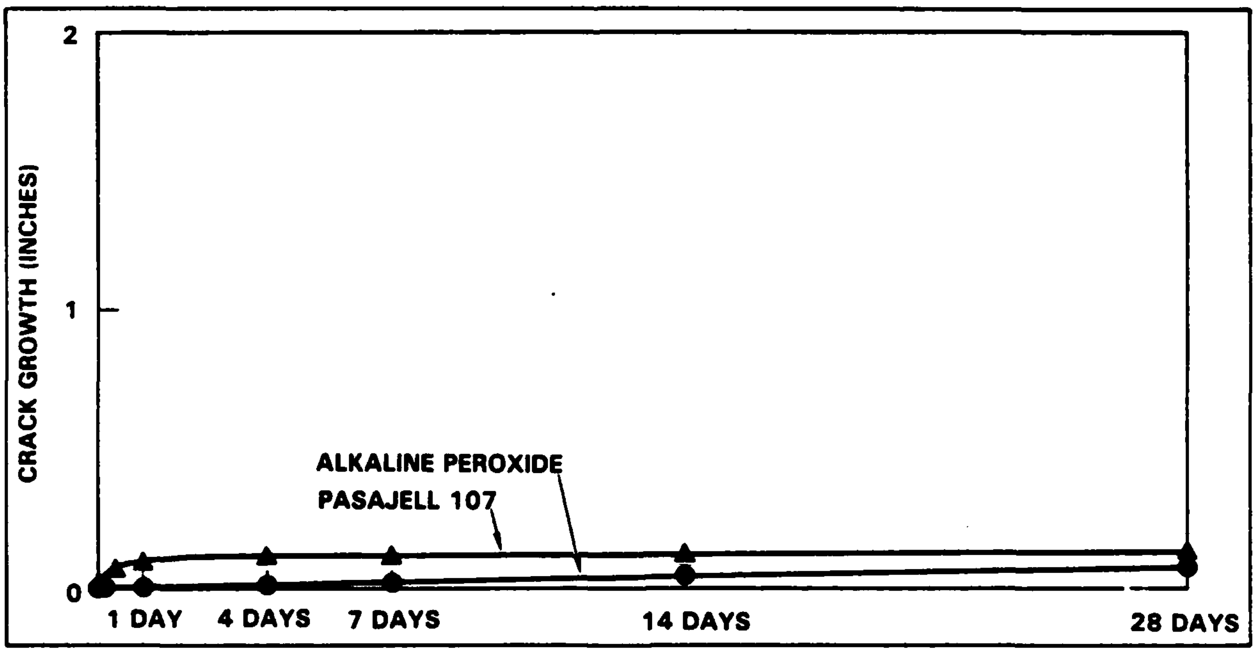

Figure 13. Wedge Test Crack Growth
6 Month Exposure, EA-9654, Primed

TABLE 10. TITANIUM-to-TITANIUM WEDGE TESTS (6 MONTH EXPOSURE) - RESULTS (SHEET 1 OF 2)

The wedge coupons have been identified with a code number. This number is explained below. There are four coupons per group and they are identified as -5 through -8 in each set. Coupons were conditioned *for 6 months at the same conditions as in Table 9.*

Panel Number	Surface Treatment	Primer	Adhesive
1	Alkaline Peroxide	BR127	FM300
2	Pasajell 107	BR127	FM300
3	Pasajell 107	bare	FM300
4	Pasajell 107	EA9228	EA9654
5	Pasajell 107	bare	EA9654
6	Alkaline Peroxide	EA9228	EA9654
7	Pasajell 107	EC3960	AF163
8	Alkaline Peroxide	EC3960	AF163
9	Pasajell 107	bare	AF163
10	Alkaline Peroxide	bare	EA9654
11	Alkaline Peroxide	bare	AF163
12	Alkaline Peroxide	bare	FM300

The wedge tests were performed under the following conditions:

1. $140^{0}F \pm 5^{0}F$
2. 80% relative humidity
3. Crack growth measured at 1 hr, 4 hrs, 1 day, 4 days, 7 days, 14 days and 28 days.
4. In the event of total failure of a specimen, it was removed at that time from the humidity chamber.

TABLE 10. TITANIUM-to-TITANIUM WEDGE TESTS (6 MONTH EXPOSURE) - RESULTS (SHEET 2 OF 2)

	Crack Length, Inches							
Specimen	Initial Length	After 1 Hour	After 4 Hours	After 1 Day	After 4 Days	After 7 Days	After 14 Days	After 28 Days
Panel 4								
5	3.47	3.47	3.80	3.85	3.89	3.89	3.89	3.93
6	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43
7	2.74	2.74	2.74	2.81	2.81	2.81	2.81	2.81
8	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Panel 2								
5	2.84	2.87	3.06	3.20	3.28	3.28	3.30	3.56
6	3.61	3.61	3.66	4.61	4.61	4.61	4.65	4.78
7	3.61	3.61	3.61	3.61	3.67	3.73	3.74	3.82
8	3.49	3.49	3.49	3.51	3.51	3.51	3.58	3.63
Panel 1								
5	2.51	2.53	2.54	2.55	2.57	2.57	2.57	2.58
6	1.85	1.86	1.88	1.88	1.88	1.88	1.88	1.89
7	2.36	2.36	2.36	2.39	2.42	2.42	2.42	2.42
8	2.50	2.50	2.55	2.55	2.55	2.55	2.55	2.59
Panel 12								
5	4.39	4.41	4.43	4.43	4.43	4.43	4.43	4.47
6	4.04	4.04	4.04	4.04	4.06	4.06	4.06	4.09
7	4.37	4.52	4.57	4.57	4.57	4.57	4.57	4.59
8	4.78	4.78	4.78	4.80	4.80	4.83	4.83	4.93
Panel 6								
5	3.70	3.70	3.72	3.72	3.72	3.72	3.72	3.74
6	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.56
7	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.90
8	2.68	2.68	2.68	2.70	2.74	2.77	2.81	2.86
Panel 5								
5	2.49	2.49	2.49	2.49	2.54	2.54	2.54	2.62
6	2.46	2.46	2.53	2.53	2.54	2.54	2.54	2.64
7	2.59	2.59	2.59	2.59	2.65	2.65	2.65	2.69
8	2.65	2.65	2.65	2.65	2.67	2.69	2.69	2.71
Panel 10								
5	2.52	2.52	2.52	2.56	2.58	2.61	2.65	2.69
6	2.61	2.61	2.62	2.62	2.65	2.68	2.68	2.76
7	2.59	2.62	2.65	2.65	2.69	2.69	2.69	2.77
8	2.72	2.72	2.72	2.72	2.73	2.73	2.73	2.79

CONCLUSIONS

The following conclusions may be drawn from this program:

- The initial bond strength provided by the use of the alkaline peroxide treatment is comparable to that provided by the use of Pasajell 107.
- The bond durability of alkaline peroxide treated specimens exposed to elevated temperature and humidity greatly exceeds that provided by the Pasajell 107 treatment.
- The bond strength of a titanium-to-graphite bond is limited by the low interlaminar shear strength of graphite composites.
- The bond strength provided by the EA-9654 adhesive is less significantly affected by cleaning treatments and primer usage than either the AF-163 or the FM-300 adhesive.
- The 250°F curing adhesive, AF-163, provides a less durable bond than do the two 350°F curing adhesives.

RECOMMENDATIONS FOR FUTURE WORK

The alkaline peroxide pre-bond cleaning treatment requires additional study in the areas of extended out-time storage capability (6 months to 5 years) in both a humidity chamber and a beach exposure environment. In addition, bond sensitivity to various solvent exposures should be evaluated. The peel strength of alkaline peroxide treated specimens needs to be determined and compared to conventionally used cleaning treatments - both initial peel strength and after elevated temperature and humidity exposure.

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