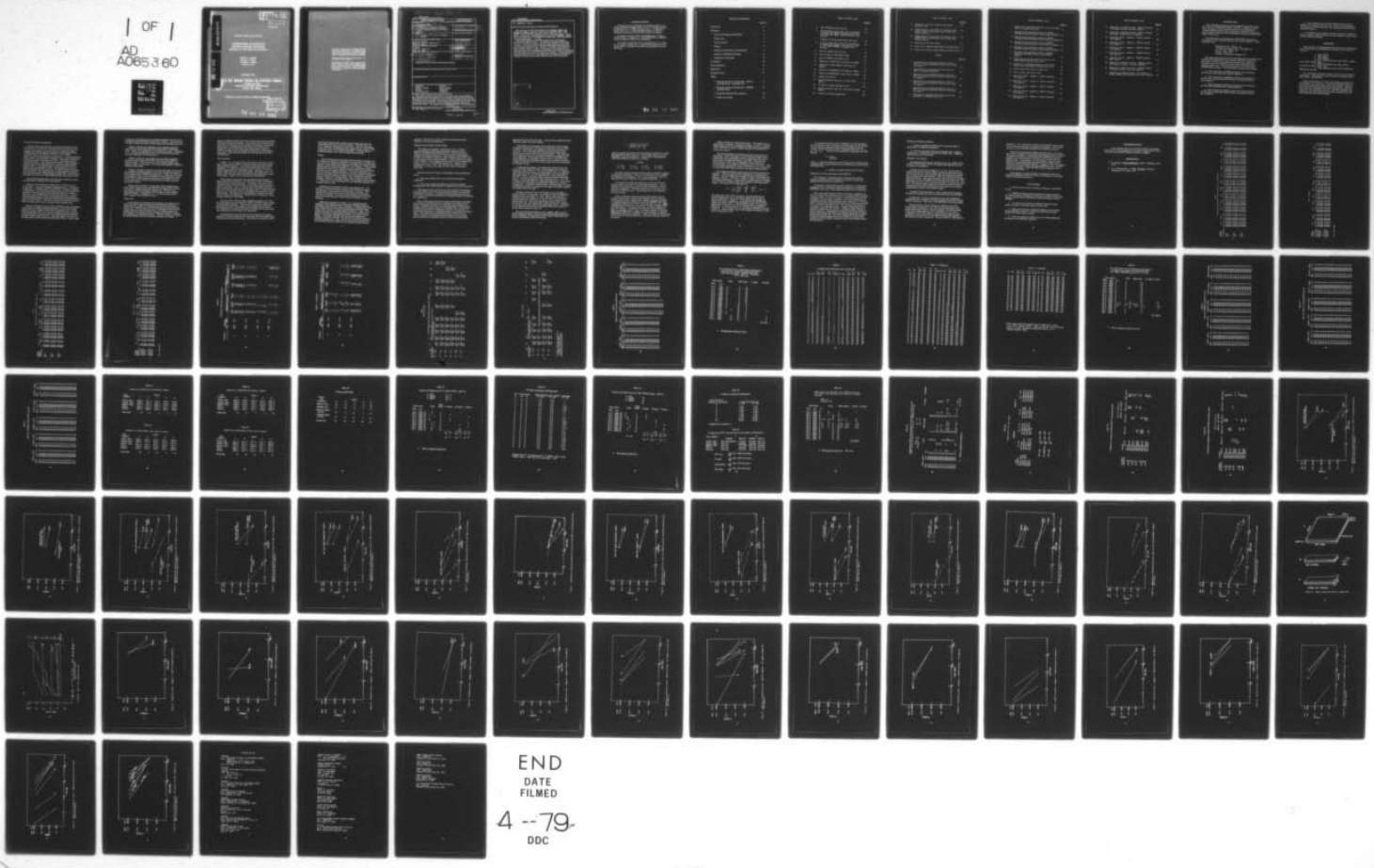
AD-A065 360 ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND DOVER--ETC F/G 11/1
A ROUND-ROBIN EVALUATION OF ADHESIVE BONDING PROCESSES RELATED --ETC(U)
NOV 78 R F WEGMEN, W J RUSSELL, E A GARNIS

UNCLASSIFIED ARLCD-TR-78047 SBIE-AD-E400 268 NL

1 OF 1
AD
A065 360



END
DATE
FILMED
4 -79
DDC

LEVEL II (12)

AD

AD-E400 268

TECHNICAL REPORT ARLCD-TR-78047

A ROUND-ROBIN EVALUATION OF ADHESIVE BONDING PROCESSES RELATED TO THE SHELTER INDUSTRY

RAYMOND F. WEGMAN
WILLIAM J. RUSSELL
ELIZABETH A. GARNIS
DAVID W. LEVI

NOVEMBER 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

Destroy this report when no longer needed. Do not return to the originator.

The citation in this report of the names of commercial firms or commercially available products or services does not constitute official endorsement or approval of such commercial firms, products, or services by the United States Government.

(18) SBIE (19) AD-E400 268

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) ARLCD-TR-78047 — 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) A Round-Robin Evaluation of Adhesive Bonding Processes Related to the Shelter Industry.	5. TYPE OF REPORT & PERIOD COVERED (9) Technical rept.,
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. F. Wegman, D. W. Levi, W. Russell, E. A. Garnes	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander, ARRADCOM Applied Sciences Div (DRDAR-LCA-OA) Dover, NJ 07801	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS (12) 87p.
11. CONTROLLING OFFICE NAME AND ADDRESS Commander STINFO Div (DRDAR-TSS) Dover, NJ 07801	12. REPORT DATE (11) November 1978
	13. NUMBER OF PAGES 86
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (10) Raymond F./Wegman, William J./Russell, Elizabeth A./Garnis David W./Levi	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adhesives	Shelters
Adhesive bonding	Shear strength
Bonding	Wedge test
Honeycomb panel	Durability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Metal parts of 5052 H 34 and 6061 T-6 aluminum alloys were supplied to five companies with the request to treat the parts in their production cleaning facilities. A portion of the parts were to be bonded as prepared and others were to be primed and then bonded. The standard cleaning method was the FPL etch. The primer used was BR 127, with two companies supplying extra panels bonded with FM 47. The adhesive used was ~~Reliabond~~ Reliabond 7114, with the exception

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

410 163

20. ABSTRACT Contd)

of one set which was bonded with Hysol En 9601 adhesive.

Both lap shear and wedge test panels were prepared, bonded, and supplied for testing. Lap shear tests were run at 23°C (73°F), 60°C (140°F) and 93°C (200°F). Lap shear tests at 60°C after 100 hr and 1000 hr immersion in 60°C water were run to predict durability. ASTM D 2919 durability tests at 60°/95%RH and wedge tests at 60°C/95-100%RH were also carried out.

The results indicate that the FM 47 primer is not as thickness-sensitive as the BR 127 primer. The 5052 H-34 aluminum alloy is not as sensitive to stress-corrosion cracking at the interface as is the 6061 T-6 alloy. The use of a primer does not significantly improve the durability of bonds to 5052H-34 alloy. However, to improve the durability of bonds to 6061 T-6 alloy, a primer is necessary. There seems to be no significant difference in durability between 5052 H-34 and 6061 T6 aluminum joints which have only been FPL etched before bonding. The study indicated statistical differences in the bonds obtained as fabricated by the different companies, but the cause of these differences has not been identified.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Mr. R. E. Austin of Goodyear Aerospace Corp., Mr. D. R. Biddle of Parsons of California, Mr. G. White of Nordam, Mr. P. B. Goodrich of Hexcel, and Dr. O. S. Tuttle (deceased) and Mr. D. Moore of Brunswick in getting the test specimens treated and prepared.

The authors would also like to acknowledge Capt. J. Sugg of AFCEC and Mr. J. Siegel of U.S. Army NARADCOM for supplying the funds required to conduct this investigation.

The authors would further like to acknowledge Mr. E. S. Duda, Mr. K. Gerlach, and Mrs. M. C. Ross for their assistance in the various phases of testing and evaluation and preparation of data for this report.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

TABLE OF CONTENTS (cont)

FIGURES

TABLE OF CONTENTS (cont)

TABLE OF CONTENTS (cont)

INTRODUCTION

This investigation was sponsored through the joint effort of the Air Force Civil Engineering Center (AFCEC), Tyndall Air Force Base, Florida; U. S. Army Natick Research and Development Command (NARADCOM), Natick, Maine and conducted by the U. S. Army Armament Research and Development Command (ARRADCOM), Dover, New Jersey.

The metal parts were supplied by ARRADCOM and prepared and bonded by five companies related to the shelter industry. These companies were:

Brunswick Corp., Marion, VA
Goodyear Aerospace Corp., Litchfield, AZ
Hexcel Corp., Dublin, CA
Nordam, Tulsa, OK
Parsons of California, Stockton, CA

The metal parts were sent to the companies whose representatives volunteered to participate in the program, with the request that the parts be treated in the production facility of the companies. The parts were to be bonded into finger panels consisting of four lap shear specimens. The bonded panels were to be returned to ARRADCOM for testing. The total number of specimens included:

a. Forty specimens of 5052H34 aluminum alloy treated via the FPL etch and bonded with a shelter adhesive.

b. Forty specimens of 5052H34 aluminum alloy treated via the FPL etch, primed with BR127 primer, and bonded with the same adhesive.

c. Forty specimens of 6061T-6 aluminum alloy treated via the FPL etch and bonded with a shelter adhesive.

d. Forty specimens of 6061T-6 aluminum alloy treated via the FPL etch, primed with BR127 primer, and bonded with the same adhesive.

e. Two companies also received sufficient metal parts to prepare forty specimens of each alloy, which were to be treated the same as the rest of that alloy, but replacing the BR127 primer with FM47 primer.

f. In addition, each company received metal parts of 6061T-6 alloy to prepare wedge test panels for each variable, namely etched and both etched and primed.

DISCUSSION

Upon receipt, the bonded panels were marked for identification, cut into specimens, and designated for testing. Tests were conducted at:

1. 23°C (73°F).
2. 60°C (140°F).
3. 93°C (200°F).
4. 60°C (140°F) while wet, after 100 hr immersion in 60°C (140°F) water .
5. 60°C (140°F) while wet, after 1000 hr immersion in 60°C (140°F) water .
6. Under constant stress at 60°C (140°F) and 95% RH until failure.

The control data is shown in tables 1 and 2 for test conditions 1 through 5. Table 3 lists the time to failure at constant stress, 60°C (140°F) and 95% RH.

Eyeball examination of the data in the tables was found to be very difficult, and, therefore, a statistical examination was conducted and is discussed in detail later in this report. However, the preliminary examination of the data did appear to show that there were two groupings of the data. The five companies were contacted, and it was found that four of the companies used tap water while one used deionized water.

Test for Prediction of Durability

The hot water soak test used to predict the durability of the bonded joints is one that was developed under joint studies sponsored by Troop Support and Aviation Materiel Readiness Command (TSARCOM) and the Army Material Evaluation Program controlled by the Army Materials and Mechanics Research Center (AMMRC). In this test, lap shear specimens are placed in a tank of deionized water at 60°C in an unstressed condition. One group of specimens is allowed to soak in the water for 100 hr while another group soaks for 1000 hr. After the prescribed time the specimens are removed from the tank and placed in a container which contains water at 60°C. The container with the water and specimens is placed in the test chamber at 60°C. One specimen at a time is removed and placed in the test grips. A thermocouple is attached to the specimen. The temperature of the specimen is monitored; when the temperature of the specimen reaches 60°C, the specimen is loaded at a rate of 16.6 Mpa (2400 psi/min) until failure occurs.

The test data obtained from the above test is plotted on semi-log graph paper, plotting time versus stress.

Another set of specimens is loaded into an ASTM-D2919 type stress fixture and a load is placed on the specimens. The fixture is placed in a chamber at 60°C and 95% RH. The time to failure is determined. The data obtained under stress at 60°C and 95% RH is plotted on the same graph as that obtained from the hot water soak test. Only a single load is used in the stress test. A line is drawn through the time to failure at that load which is parallel to the line drawn through the data points obtained at 100 and 1000 hours soak in the 60°C water. This line is used as the prediction line for what one might expect from a variable stress durability test.

Figures 1 through 5 show the 60°C (140°F) hot water degradation curves and the resultant predicted durability curves for the joints prepared by each company using 6061T-6 aluminum alloy. In the case of company B (fig. 2), it was not possible to draw a prediction curve for the FPL etched joints since no degradation was found in the 60°C (140°F) water soak test. This was unusual and could only be explained by the data spread obtained after 100 hr of water soak.

It was also not possible to draw predicted durability curves for the specimens made with BR127 primer (fig 3 and 4). The primer was too thick, and primer failure caused rather flat degradation curves.

Figure 6 shows the comparison of the predicted durability curves for the joints made with FPL etched 6061T-6 aluminum alloy. There is no explanation for the spread in curves. Companies A, C, D and E used tap water and it can be postulated that there was some difference in the tap waters.

Figure 7 shows the comparison of the predicted durability curves for joints made with the FPL etch and primed 6061T-6 aluminum alloy. The use of primer when properly applied does appear to help, in most cases, to increase the durability of 6061T-6 aluminum alloy joints.

Figures 8 through 12 show the hot water degradation curves and the resultant predicted durability curves for the joints prepared by each company using 5052H34 aluminum alloy. Again, as in the case of the 6061T-6 alloy, it was not possible to draw prediction curves for the BR127 primed specimens prepared by companies C and D as the primer was too thick and failure after the water soak test was primer failure.

Figures 13 and 14 show comparisons of the predicted durability curves for the joints made with FPL etched and FPL etched and primed 5052H34 aluminum, respectively. With this alloy there appears to be an indication that the type of water used may affect the results. Companies A, C, D, and E used tap water while company B used deionized water.

Wedge Test

A test capable of evaluating the durability of an adhesive joint without the use of expensive jigs and environmental chambers which will give results in a reasonable period has been sought for a long time. With the advent of fracture toughness studies and the double cantilever beam test specimen, it is a logical step to the development of the wedge test for evaluating the influence of interface variables on adhesive durability. This test consists of bonding two plates together and then cutting the laminate into strips. A

spacer or wedge is forced into one end of the strip and the assembly is put into the test environment. The growth of the crack down the bond line is monitored, and the results are plotted as crack length versus time. A semilog plot of the data gives a usable curve. During the course of this round-robin test program, panels of 6061T-6 aluminum were processed and bonded at the participating companies. They were then returned to this laboratory for test and evaluation.

Test Procedure

Panels 7 x 8 1/2 inches (178 x 216 mm) by 1/8 inch (3.2 mm) thick were cut out of 6061T-6 aluminum alloy sheet and stamped with identifying numbers. A line was scribed across the narrow dimension 2 inches (51 mm) from the end in such a way as to divide the panel into two rectangular areas. One area, 7 x 6 1/2 inches (178 x 165 mm), was to be bonded. The other area, 7 x 2 inches (178 x 51 mm), was to be covered with a teflon film to prevent bonding. Figure 15A is a drawing of a bonded panel.

After bonding, the panels were returned to this laboratory where they were cut into six 1 x 8 1/2 inch (25 x 216.1 mm) strips. Three of these strips were tested. The edges of the strips were carefully milled so the progression of the crack could be monitored with a microscope. The 2-inch (51-mm) wide teflon film strip was removed from the end of the test strip, and a 1/8-inch (3.2-mm) thick x 1 x 1/2 inch (25 x 13 mm) rectangular block of 6061T-6 alloy was inserted. The edges of the rectangle were carefully set flush with the edges of the specimen. Figure 15B is a drawing of a strip ready for insertion of the wedge.

The test strips, with the wedge installed as shown in fig. 15C, were then placed in a test chamber at 60°C and 100% relative humidity (condensing moisture). The test environment was achieved by placing heated water in the bottom of the insulated test chamber. The temperature was thermostatically controlled and the specimens were positioned over the water on a glass plate.

The specimens were removed from the chamber at intervals, wiped dry, and the locations of the crack tips were determined using a 40 power binocular microscope. The location was marked on the

side of the specimen with a sharp scribe and the specimen was immediately returned to the test chamber. After the test runs were completed, the specimens were dried and the crack lengths at the end of each test interval were measured and recorded. The arithmetic mean $\bar{x}$, the standard deviation δ, and the percent standard deviation $\delta/\bar{x}$ were calculated and recorded.

Results

As can be seen from the results shown in table 4 and figure 16, the wedge test results are different for the specimens received from each of the four different companies even though the materials (alloy, adhesive, and primer) were supposed to be the same. These results indicate that the method of bonding is a very significant variable. Samples A^O and A' from company A had the least crack growth and also the lowest % standard deviation. This set of specimens not only were the best tested, but also had the least variance, indicating that the procedure used by company A gave consistently excellent results. Sample B^O, without primer, from company B had good durability and was only slightly inferior to the samples from company A. When primer was used (sample B'), the durability degraded to a ranking of poor to fair.

Samples from companies C and D were graded poor. The sample C' (with primer) was rated fair after 8 hours of testing, but degraded to poor within the first 24 hours of testing. The samples from company E were both rated as good to fair after 120 hours of testing. The sample made without primer (E^O) was good to excellent during the first 24 hours of testing, but then degraded.

Taking these results as a whole, it is concluded that the durability of an adhesive bond is extremely dependent upon the conditions under which the bond is prepared. A quick study of the data indicates that in four cases the specimens prepared using primer were inferior to those prepared without it. Thus, if the results obtained from specimens prepared from company A are ignored, it could be concluded that the use of a primer is detrimental. The results obtained from specimens prepared by company A indicate, however, that the use of a primer results in the most durable bond. Thus, the use of a primer produces the most durable bonds providing that the bonding procedure used is

optimum. The use of a primer requires more than the usual amount of care during processing.

Statistical Examination of Round Robin

Five different companies, designated A, B, C, D and E, prepared adhesive bonded specimens using aluminum alloys 6061T-6 and 5052H34 with Reliabond 7114. There was one exception to the latter statement, in that company E used adhesive EA 9601 with 5052H34 aluminum. Each company used an FPL etch as well as at least one primer (BR127). C and E also used a second primer (FM47). Four individual specimens (3 in a few cases) were tested to failure in the ARRADCOM Laboratories. The tests were accomplished at 23°C (73°F), 60°C (140°F), 93°C (200°F), and at 140°F after a 100-hour water soak and 140°F after a 1000-hour water soak.

After the data were obtained and tabulated, several questions arose:

1. Were there differences in the results from different companies?

2. Were there significant differences between resultant strengths after FPL pretreatment as compared to the use of primers?

Eyeballing the data to answer the above questions was difficult, since the results were rather extensive and tended to be somewhat contradictory in places. A simple statistical approach seemed to be in order, since this would permit the setting of objective standards for comparison.

Since comparisons between fabricators and between treatments were desired, the Wilcoxon sum of ranks test was applied (refs 1 and 2). In applying this test, all of the data were arranged in increasing order from the lowest to the highest value, as illustrated in table 5, for the 6061T-6 Reliabond 7114-FPL etch results. In this table the fabricator is identified beside each numerical strength value. The actual test is illustrated in table 6 where the last column of table 5 is reproduced and the Wilcoxon sum of ranks test is performed to determine if the B results are significantly

different from the rest of the data. This test was repeated for each fabricator under each test condition.

Using table 6 as an example of the application of the method, the data are divided into two groups and the tally column is filled as shown. Rank values are obtained by numbering as shown in column 3. It is to be noted that numbering must go both ways, from bottom to top as well as from top to bottom. The reason for this is that there may be a significant difference on either the low or the high side. In any case, the sum of the A rank or B rank column that gives the smallest number is the one used in the test. In table 6, this sum is R = 12 as shown and comes from numbering from bottom to top.

In determining whether B is significantly different from the rest of the data, table 7 is used. In the present case, there are 14 values in the A tally ($n_A = 14$) and 4 in the B ($n_A = 4$). Entering table 7 at 4 and 14 for n_A and n_B, respectively, it is immediately observed that for R = 12, P is less than 1%. This means that in less than 1 case in 100 these results would have been obtained by chance. Usually anything less than 1 chance in 20 (i.e., P = 5%) is taken to mean that there is a significant difference. In this case the B data are interpreted as significantly different from the remaining data. It should be observed that in entering table 7 it makes no difference whether n_A is taken as the larger or smaller number; the results will be the same.

Another example of the use of Wilcoxon's sum of ranks is shown in table 8. In this case, the smaller R value is obtained by numbering from the bottom up. Note that in case of ties the average is used for ranking. It turns out that R = 27.5 and upon entering table 7 at 4 and 16 for n_A and n_B, it is seen that P is greater than 10%. This means that there is better than 1 chance in 10 that B could have attained this ranking by chance. Obviously, we can assume that there is no significant difference between B and the other samples in this case.

With up to 20 measurements in each sample, table 7 can be used as discussed above. With more than 20 measurements in one or both samples, the significance of the smaller rank total (R) is found by calculating Z from the formula:

$$Z = \frac{n_R\,(n_A + n_B + 1) - 2R}{\left(\frac{n_A n_B (n_A + n_B + 1)}{3}\right)^{\frac{1}{2}}}$$

where n_R equals the number of measurements in whichever sample possesses the smaller rank total. It may equal either n_A or n_B depending on the circumstances. Values of Z corresponding to important probability levels are as follows:

Z Table

P = 10%	P = 5%	P = 1%	P = 0.2%
Z = 1.64	Z = 1.96	Z = 2.58	Z = 3.09

The interpretation derived from this table is perfectly analogous to the earlier discussion. Thus, if Z is less than 1.96, a significant difference is not proven. But if Z is more than 1.96, P is less than 5% and the difference is probably significant.

In comparing the different fabricators, all of the FPL etch data are treated as shown in the previous illustrations. The remainder of the raw data are shown in table 9 ranked according to numerical magnitude. Similarly tables 10 and 11 show the raw data for the BR127 primer. These results are also evaluated in the same manner.

Tables 12 through 15 summarize the final results for the company comparison. Based on the Wilcoxon sum of ranks test, each company at each condition was ranked as average, meaning no significant difference from the rest of the data ($P > 5\%$), high, a significant difference ($P < 5\%$) on the high side, and low, significant difference ($P < 5\%$) on the low side. In order to better visualize the results, an arbitrary point value of 3 was assigned to high, 2 to average, and 1 to low. This point ranking, it should be emphasized, was purely an artifact to make it easier to visualize differences between the companies. Thus, the higher the point total, the stronger the bonds produced by a particular company relative to the others.

Table 16 shows the overall point totals. The samples from A overall gave, markedly, the best test results. However, D used a different adhesive with the 5052H34 (EA 9601 instead of Reliabond 7114). This did not appear to affect company D's results in an observable manner.

The final comparison was between the FPL etch and the use of primers. Only in the case of C and E did there appear to be enough data to get a reasonable direct comparison, and, even in these cases, two different primers were used. Since the two primers and the FPL etch corresponded to three samples of measurements, the Kruskal and Wallis test (ref 1) was used. This test essentially extended the range of Wilcoxon's sum of ranks test to cases where there were more than two sets of measurements.

The Kruskal and Wallis method will be described with specific examples. The first step involves tabulations, as illustrated in table 17. The data values are arranged in order of increasing test values in column 1. The tally, A ranks, B ranks, and C ranks are tabulated as illustrated. In this case it is only necessary to number in one direction, either in order of increasing or decreasing data values. The value of X^2 is calculated by:

$$X^2 = \frac{12}{N^2 + N}\left(\frac{R_A^2}{n_A} + \frac{R_B^2}{n_B} + \frac{R_C^2}{n_C}\right) - 3(N + 1)$$

The higher the value of X^2, the greater the likelihood that the observed differences are not just from chance, but are due to genuine differences. Again, P = 5% is used as the dividing line. Table 18 is used to estimate the magnitude of P for the X^2 value. Applying the value of $X^2 = 1.76$ calculated in table 17 to table 18, shows that P is greater than 10% so that there is no significant difference. A case where there is a significant difference is shown in table 19. The procedure used in this example is identical to that shown immediately above.

In experiments where we are comparing 3 or more samples, as in the present case, the difference between any 2 of the samples can be tested for significance quite easily provided that all the samples contain the same number of measurements (ref 1) (i.e., $n_A = n_B = n_C$). The test is accomplished by calculating the value of K by

$$K = \frac{d-0.8}{n\,(n)\,1/2}$$

where d = difference between the rank totals of the 2 samples being compared (these totals being those in the tabular part of the Kruskal and Wallis test).

n = number of measurements in each sample.

Significance is then estimated by using table 20.

If the number of measurements is not the same in all the samples, individual pairs of samples can still be compared by applying Wilcoxon's sum of ranks test.

A summary of these tests is shown in table 21. In this table, average denotes no significant difference between the treatments. In all other cases there were significant differences as indicated.

Due to the small amount of data in each case, comparison of FPL etch and the use of primers for A, B, and D seemed to require grouping of data. In order to minimize basic differences between companies, the high value companies (A, E) were grouped as one population and those giving generally lower values (B, C, D) as the other. Within each group, the Wilcoxon sum of ranks test was used to compare FPL with primer use. The procedure was perfectly analogous to that described earlier. Sample comparisons are illustrated in tables 20, 22, and 23. A summary of the results is shown in table 24. Examination of tables 21 and 24 would seem to indicate that the use of primers gave results as good as or a little better than the FPL etch. The value labeled "FPL Intermediate" in table 21 resulted because the primer (BR127) was put on the specimen much too thickly, leading to much lower strength values for this primer.

Summary of Statistical Results

1. There are statistical differences in bond strengths of specimens from different companies.

2. The use of primers (if properly applied) gave strengths as good as or a little better than the use of FPL etch. Additional experiments are recommended.

Durability Test Results

The data obtained from the durability tests, per ASTM D 2919, at 60°C (140°F) and 95 + % RH are shown in the tables 25 and 26 and figures 17 through 31.

A study of the curves in figures 17, 18, 19, and 21 tends to indicate that the FPL etched, 6061T-6 aluminum specimens which were not primed are more dependent upon the stress level applied than are those which were primed. This can be detected from the slope of the lines. This may be related to the rate that the moisture penetrates the joint and affects the oxide layer under the bond. The phenomenon may be a form of stress/corrosion cracking at the interface. The primed surface appears to retard the stress/corrosion cracking at the interface and the failure becomes one of a stress-plasticization reaction of the adhesive itself.

Company D used hard water, and the results (fig 20) indicate that both the unprimed and primed specimens have poor durability.

In figure 22, it can be seen that there are some differences between the four companies' specimens prepared using FPL etched, 6061T-6 aluminum. The cause of the difference is not discernable.

Figure 23 shows that the differences detected in the FPL etched, 6061T-6 specimens (fig 22) are carried through to the primed specimens; that is, a general ranking of the most durable to the least durable appears to be companies A, E, B, and C. Companies C and B also appear to have control problems in the application of the primer; too much BR127 primer was applied to the surfaces by these companies. The use of FM 47, vinyl phenolic

primer (C' + E'), does seem to improve the durability of the joints as to the stress/corrosion cracking at the interface. This type of primer is not as thickness-sensitive as the BR127 primer is.

When the adherends are 5052H34 aluminum alloy, fig 24-30, there does not appear to be the sharp distinction between the primed and unprimed surfaces, indicating that the 5052H34 alloy is less sensitive to stress/corrosion cracking at the interface that the 6061T-6 alloy. Companies A, E, and B appear to have the least problems in preparing bonded specimens; again ranking in this order as to the most durable surfaces. Company C (fig 10) appears to have some problem with preparing 5052H34 aluminum, whether primed or unprimed. Again, the FM 47 primer appears to be better than the BR127.

From the data, it is not possible to distinguish between the unprimed 5052H34 and 6061T-6 alloys as to durability of the joints. Figure 32 illustrates this point.

CONCLUSIONS

1. FM 47 primer is not as thickness-sensitive as the BR127 primer.

2. 5052H34 aluminum alloy specimens are not as sensitive to stress/corrosion cracking at the interface as 6061T-6 specimens. Use of a primer doesn't significantly improve durability bonds to 5052H34.

3. To improve the durability of 6061T-6 adhesive bonded joints, a primer is necessary after the FPI etch.

4. There seems to be no significant difference in durability between 5052H34 and 6061T-6 aluminum joints when they are simply FPL etched before bonding.

5. There are statistical differences in the bonds obtained as fabricated by the different companies.

RECOMMENDATION

The companies will have to develop improved techniques and controls for the application of primers to assure that no more than the recommended thickness of primer is applied.

REFERENCES

1. R. Langley, Practical Statistics, Dover, Publishers, NY, 1971.

2. R. R. Stokal and F. J. Rohlf, Biometry, Freeman, Publishers, NY, 1969, p 391.

Table 1

Original lap shear strength data - 6061T-6 aluminum alloy - Reliabond 7114

Company	A				B				C				D				E					
Treatment	FPL		BR127		FPL		BR127		FPL		BR127		FM47		FPL		BR127		FPL		BR127		FM47	
Test condition	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa
	5520	38.1	5160	35.6	5420	37.3	4670	32.2	4020	27.7	4950	34.1	3990	27.5	3950	27.2	4040	27.9	4990	34.4	5080	35.0	5570	38.4
(73°F)	5480	37.8	5300	36.5	5010	34.5	4600	31.7	4010	27.6	4650	32.1	4090	28.2	4200	29.0	3990	27.5	4770	32.9	5460	37.6	5580	38.5
23°C	5550	38.3	5190	35.8	5450	37.6	4780	33.0	3940	27.2	3750	25.9	4270	29.4	4730	32.6	4140	28.5	4890	33.7	5160	35.6	5570	38.4
	5500	37.9	5100	35.2	5650	39.0	4560	31.4	--	--	4190	28.9	--	--	4410	30.4	4250	29.3	--	--	5380	37.1	5610	38.7
	5510	38.0	5190	35.8	5380	37.1	4650	37.1	3990	27.5	4390	30.3	4120	28.4	4320	29.8	4110	28.3	4880	33.6	5270	36.3	5580	38.5
	5370	37.0	5120	35.3	4730	32.6	4610	31.8	4210	29.0	3730	25.7	3620	25.0	4470	30.8	4150	28.6	4480	30.9	5190	35.8	5210	35.9
(140°F)	5360	37.0	5520	38.1	4570	31.5	4060	28.0	3970	27.4	4100	28.3	4280	29.5	4130	28.5	4490	31.0	4350	30.0	5120	35.3	5250	36.2
60°C	5540	38.2	5540	38.2	4950	34.1	3000	20.7	3940	27.2	4070	28.1	4480	30.9	4440	30.6	4390	30.3	4250	29.3	4740	32.7	5350	36.9
	5380	37.1	5570	38.4	4770	32.9	2880	19.9	--	--	4500	31.0	--	--	4140	28.5	4360	30.1	--	--	4860	33.5	5360	37.0
	5410	37.3	5440	37.5	4760	32.8	3640	25.1	4040	27.9	4100	28.3	4130	28.5	4300	29.6	4350	30.0	4360	30.1	4980	34.3	5290	36.5
	3080	21.2	3660	25.2	3380	23.3	2930	20.2	5470	37.7	4000	27.6	3510	24.2	2020	13.9	3340	23.0	3580	24.7	3580	24.7	4010	27.6
(200°F)	3290	22.7	3800	26.2	3700	25.5	2800	19.3	5400	37.2	3960	27.3	3190	22.0	2310	15.9	3320	22.9	3760	25.9	3780	26.1	3890	26.8
93°C	3310	22.8	3610	24.9	3810	26.3	3000	20.7	5030	34.7	3440	23.7	4240	29.2	2590	17.9	3240	22.3	3780	26.1	3990	27.5	3720	25.6
	3460	23.8	3500	24.1	3750	25.9	3120	21.5	5040	34.8	3400	23.4	4200	29.0	2990	20.6	3370	23.2	3520	24.3	3920	27.0	3840	26.5
	3290	22.7	3640	25.1	3660	25.2	2960	20.4	5240	36.1	3700	25.5	3790	26.1	2480	17.1	3320	22.9	3660	25.2	3820	26.3	3870	26.7

Table 1 - Continued

Company	A				B						C				D				E			
Treatment	FPL		BR127		FPL		BR127		FPL		BR127		FM47		FPL		BR127		FPL		BR127		FM47	
Test condition	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa
(140°F) 60°C	4910	33.9	5230	36.1	3930	27.1	3690	25.4	2780	19.2	3060	21.1	3500	24.1	3260	22.5	2180	15.0	3790	26.1	4220	29.1	4500	31.0
after 100 hr	5090	35.1	5020	34.6	3650	25.2	3330	23.0	2800	19.3	3060	21.1	3490	24.0	3310	22.8	2300	15.9	3880	26.8	4730	32.6	4400	30.3
(140°F) 60°C	5200	35.8	5060	34.9	3150	21.7	2960	20.4	3000	20.7	2710	18.7	3820	26.3	3570	24.6	2420	16.7	3670	25.3	4580	31.6	4630	31.9
water soak	4860	33.5	5210	35.9	2850	19.7	2680	18.5	--	--	2540	17.5	--	--	3440	23.7	2240	15.4	--	--	4720	32.5	4740	32.7
	5020	34.6	5130	35.4	3400	23.4	3170	21.9	2860	19.7	2840	19.6	3600	24.8	3400	23.4	2290	15.8	3780	26.1	4560	31.4	4570	31.5
(140°F) 60°C	2810	19.4	3250	22.4	3660	25.2	2970	20.5	2100	14.5	3080	21.2	3040	21.0	1660	11.4	2150	14.8	2900	20.0	4080	28.1	3440	23.7
after 1000 hr	2260	15.6	3620	25.0	3500	24.1	2770	19.1	2030	14.0	3600	24.8	3120	21.5	1730	11.9	2030	14.0	2860	19.7	4240	29.2	3440	23.7
(140°F) 60°C	3290	22.7	3800	26.2	3300	22.8	2810	19.4	2230	15.4	2550	17.6	3260	22.5	1540	10.6	2370	16.3	3070	21.2	4090	28.2	3840	26.5
water soak	3170	21.9	3510	24.2	3120	21.5	2880	19.9	--	--	2720	18.8	--	--	1760	12.1	2210	15.2	--	--	4050	27.9	3680	25.4
	2880	19.9	3550	24.5	3400	23.4	2860	19.7	2120	14.6	2990	20.6	3140	21.7	1670	11.5	2190	15.1	2940	20.3	4120	28.4	3600	24.8

Note 1 - Metal Failure

Table 2

Original lap shear strength data - 5052H34 aluminum alloy

Company	A				B				C						D				E					
Treatment	FPL		BR127		FPL		BR127		FPL		BR127		FM47		FPL		BR127		FPL		BR127		FM47	
Adhesive		R 7114				R 7114				R 7114						R 7114				EA 9601				
Test condition	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa
	4630	31.9	4560	31.4	4270	29.4	3970	27.4	3350	23.1	3340	23.0	4020	27.7	2950	20.3	2840	19.6	4620	31.9	4520	31.2	4680	32.3
(73°F)	4770	32.9	4470	30.8	4210	29.0	3760	25.9	3725	25.7	3100	21.4	4470	30.8	3380	23.3	3530	24.3	4580	31.6	4460	30.8	4610	31.8
23°C	4740	32.7	4470	30.8	4130	28.5	3920	27.0	3750	25.9	2840	19.6	4500	31.0	3830	26.4	3110	21.4	4570	31.5	4650	32.1	4410	30.4
	4820	33.2	4050	27.9	4230	29.2	3800	26.2	--	--	3100	21.4	--	--	3270	22.5	2670	18.4	4700	32.4	4540	31.3	4610	31.8
	4740	32.7	4390	30.3	4210	29.0	3860	26.6	3610	24.9	3100	21.4	4330	29.9	3360	23.2	3040	21.0	4620	31.9	4540	31.3	4580	31.6
	4510	31.1	4520	31.2	4040	27.9	3600	24.8	2740	18.9	4110	28.3	4460	30.8	3450	23.8	3680	25.4	4490	31.0	4440	38.6	4250	29.3
(140°F)	4470	30.8	4560	31.4	4100	28.3	3840	26.5	3190	22.0	3400	23.4	4560	31.4	3700	25.5	3250	22.4	4510	31.1	4670	32.2	4300	29.6
60°C	4720	32.5	4640	32.0	4060	28.0	3790	26.1	2620	18.1	3690	25.4	4310	29.7	3190	22.0	3240	22.3	4550	31.4	4560	31.4	4410	30.4
	4720	32.5	4540	31.3	4010	27.6	3480	24.0	2530	17.4	4530	31.2	--	--	3140	21.7	3040	21.0	4470	30.8	4550	31.4	4610	31.8
	4610	31.8	4570	31.5	4050	27.9	3680	25.4	2770	19.1	3930	27.1	4440	30.6	3370	23.2	3300	22.8	4510	31.1	4560	31.4	4390	30.3
	3540	24.4	3540	24.4	3360	23.2	3020	20.8	2580	17.8	3630	25.0	3288	22.7	3310	22.8	2020	13.9	3220	22.2	3240	22.3	3910	27.0
(200°F)	3360	23.2	3360	23.2	3430	23.6	2980	20.5	2680	18.5	3860	26.6	3240	22.3	2960	20.4	2310	15.9	3400	23.4	3710	25.6	3800	26.2
93°C	3520	24.3	3520	24.3	3400	23.4	3120	21.5	2720	18.8	4030	27.8	3520	24.3	2460	17.0	2590	17.9	3360	23.2	3230	22.3	3960	27.3
	3560	24.5	3560	24.5	3350	23.1	3050	21.0	2760	19.0	4030	27.8	3530	24.3	3170	21.9	2990	20.6	3140	21.7	3630	25.0	3890	26.8
	3500	24.1	3500		3390	23.4	3040	21.0	2690	18.5	3890	26.8	3390	23.4	2980	20.5	2480	17.1	3280	22.6	3450	23.8	3890	26.8

Table 2 - Continued

Company	A				B				C						D				E					
Treatment	FPL		BR127		FPL		BR127		FPL		BR127		FM47		FPL		BR127		FPL		EA 9601 BR127		FM47	
Adhesive			R 7114				R 7114				R 7114						R 7114							
Test condition	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa	psi	MPa
(140°F) 60°C	4500	31.0	4380	30.2	3990	27.5	4130	28.5	2490	17.2	2350	16.2	3660	25.2	2930	20.2	2140	14.8	3880	26.8	4230	29.2	4140	28.5
after 100 hr	4570	31.5	4540	31.3	4120	28.4	4030	27.8	2310	15.9	2400	16.5	3590	24.8	3060	21.1	2270	15.7	3350	23.1	4080	28.1	4150	28.6
(140°F) 60°C	4600	31.7	4550	31.4	4100	28.3	3970	27.4	2430	16.8	2600	17.9	3390	23.4	3010	20.8	2370	16.3	3760	25.9	4150	28.6	4220	29.1
water soak	4580	31.6	4470	30.8	4180	28.8	3900	26.9	2470	17.0	2510	17.3	--	--	2920	20.1	2580	17.8	3700	25.5	4060	28.0	4380	30.2
	4560	31.4	4490	31.0	4100	28.3	4010	27.6	2430	16.8	2470	17.0	3550	24.5	2980	20.5	2340	16.1	3670	25.3	4130	28.5	4220	29.1
(140°F) 60°C	4200	29.0	3750	25.9	2490	17.2	3380	23.3	1460	10.1	2290	15.8	2630	18.1	2030	14.0	2190	15.1	3460	23.9	3890	26.8	3180	21.9
after 100 hr	4260	29.4	3930	27.1	3350	23.1	3060	21.1	1480	10.2	2240	15.4	2520	17.4	1940	13.4	1980	13.7	2900	20.0	3880	26.8	3240	22.3
(140°F) 60°C	4200	29.0	3950	27.2	3240	22.3	3520	24.3	1480	10.2	2580	17.8	2450	16.9	1740	12.0	2340	16.1	3250	22.4	3490	24.1	3240	22.3
water soak	4130	28.5	3940	27.2	3480	24.0	3650	25.2	1230	8.5	2340	16.1	--	--	2180	15.0	2200	15.2	3100	21.4	3850	26.5	3340	23.0
	4200	29.0	3890	26.8	3140	21.7	3400	23.4	1410	9.7	2360	16.3	2530	17.4	1970	13.6	2180	15.0	3180	21.9	3780	26.1	3250	22.4

Note 1 = Metal Failure

Table 3

Durability data used for prediction

Company	Stress		Time to failure, hr					
	psi	MP2	5052H34 Aluminum			6061T-6 Aluminum		
			FPL	BR127	FM47	FPL	BR127	FM47
A	2000	13.8	131	118	---	84	337	---
			148	45	---	236	281	---
			65	143	---	249	263	---
			81	67	---	243	217	---
			106	93	---	203	274	---
B	2000	13.8	21	10	---	4	56	---
			21	10	---	11	43	---
			32	19	---	14	32	---
			11	8	---	9	39	---
			21	14	---	10	43	---
C	1760	12.1	.3	---	---			
			.3	---	---			
			.2	---	---			
			.8	---	---			
			.4	---	---			
C	2000	13.8	---	.1	---	16	1	111
			---	.1	---	7	1	113
			---	.1	---	3	2	122
			---	.1	---	---	---	---
			---	.1	---	9	1	114

Table 3 - Continued

Company	Stress		Time to failure, hr					
	psi	MP2	5052H34 Aluminum			6061T-6 Aluminum		
			FPL	BR127	FM47	FPL	BR127	FM47
C	1500	10.3	---	---	2			
			---	---	4			
			---	---	2			
			---	---	---			
			---	---	3			
D	2000	13.8	.2	.2	---	.5	.8	---
			.1	25	---	.5	.7	---
			.2	13	---	.7	.7	---
			---	.3	---	.7	.7	---
			.2	10	---	.6	.7	---
E	2000	13.8	24	89	162	10	235	167
			170	7	191	6	228	58
			65	63	93	57	89	70
			18	58	133	---	90	211
			69	54	145	24	160	126

Table 4

Wedge test results

Specimen Source Co.	Primer	HR	Crack Length in mm (inches) After Hours at 60°C - 100% RH: 1/4	1/2	1	2	4	5	6	7	24	48	72	120	145	168
			Mean (X) crack length in mm (inches) - 3 tests (/x = % Standard Deviation)													
*A°	None		(1.72)	(1.97)	(2.07)	(2.09)	(2.09)		(2.09)		(2.08)	(2.08)	(2.08)			(2.08
			43.7	50.0	52.6	53.1	53.1		53.1		52.8	52.8	52.8			52.8
			0	5%	4%	4%	4%		4%		4%	4%	4%			4%
A¹	Yes		(1.63)	(1.68)	(1.70)	(1.70)	(1.70)		(1.70)		(1.72)	(1.73)	(1.74)			(1.77)
			41.4	42.7	43.2	43.2	43.2		43.2		43.7	43.9	44.2			45.0
			5%	5%	4%	4%	4%		4%		4%	4%	4%			2%
B°	None		(2.02)	(2.05)	(2.07)	(2.07)	(2.07)		(2.07)		(2.11)	(2.17)	(2.21)		(2.27)	
			51.3	52.1	52.6	52.6	52.6		52.6		53.6	55.1	56.1		57.7	
			10%	10%	9%	9%	9%		9%		11%	12%	12%		14%	
B¹	Yes		(2.22)	(2.73)	(3.51)	(4.13)	(4.14)		(4.15)		(4.18)	(4.21)	(4.22)		(4.26)	
			56.4	69.3	89.2	105	105		105		106	107	107		108	
			9%	14%	6%	6%	6%		6%		6%	6%	6%		6%	
C°	None		(4.11)	(4.39)	(4.66)	(4.94)	(5.38)	(5.47)			(5.54)	(5.55)		(5.56)		
			104	112	118	125	137	139			141	141		141		
			6%	5%	5%	7%	7%	7%			7%	7%		7%		
C¹	Yes		(2.92)	(3.05)	(3.40)	(3.61)	(3.66)	(3.68)			(4.85)	(4.95**)		(5.85**)		
			74.2	77.5	86.4	91.7	93.0	93.5			123	126		149		
			42%	45%	55%	61%	62%	63%			49%	50%		25%		

Table 4 - Continued

HR	1/4	1/2	1	2	4	5	6	7	24	48	72	120	145	168
Specimen Source Co. Primer	Mean (X) crack length in mm (inches) - 3 tests (/x = % Standard Deviation)													
D^0 None	(3.42)	(3.97)	(4.09)	(4.17)	(4.18)			(4.20)	(4.21)	(4.25)	(4.25)			(4.38)
	86.9	101	104	104	106			107	107	108	108			111
	9%	4%	5%	4%	4%			5%	5%	6%	6%			12%
D^1 Yes	(6.64)	(7.75)	(8.5)											
	169	191	216	SPECIMENS COMPLETELY DELAMINATED AFTER 1/2, 1 and 2 HOURS										
	13%	---	---											
E^0 None	(1.88)	(1.91)	(1.94)	(1.95)	(1.98)		(2.01)		(2.25)	(2.56)	(2.69)	(2.87)		
	47.8	48.5	49.3	49.5	50.3		51.1		57.2	65.0	68.3	72.9		
	3%	4%	4%	4%	5%		6%		7%	8%	11%	7%		
E^1 Yes	(2.33)	(2.71)	(2.92)	(2.95)	(2.96)		(2.97)		(2.98)	(2.99)				(3.00)
	59.2	68.8	74.2	74.9	75.2		75.4		75.7	75.9				76
	24%	15%	12%	11%	11%		11%		11%	11%				12%

*A^0 indicates Company A panel with no primer, A^1 is with primer.

**One specimen completely delaminated. 203 mm (8") was used as the value.

Table 5

Data for 6061T-6 using FPL etch

(73°F) 23°C			(140°F) 60°C			(200°F) 93°C			100 hr aging			1000 hr aging		
MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.
27.2	3940	C	27.2	3940	C	13.9	2020	D	19.2	2780	C	10.6	1540	D
27.2	3950	D	27.4	3970	C	15.9	2310	D	19.3	2800	C	11.4	1660	D
27.6	4010	C	28.5	4130	D	17.9	2590	D	19.7	2850	B	11.9	1730	D
27.7	4020	C	28.5	4140	D	20.6	2990	D	20.7	3000	C	12.1	1760	D
29.0	4200	D	29.0	4210	C	21.2	3080	A	21.7	3150	B	14.0	2030	C
30.4	4410	D	29.3	4250	E	22.7	3290	A	22.5	3260	D	14.5	2100	C
32.6	4730	D	30.0	4350	E	22.8	3310	A	22.8	3310	D	15.4	2230	C
32.9	4770	E	30.6	4440	D	23.3	3380	B	23.7	3440	D	15.6	2260	A
33.7	4890	E	30.8	4470	D	23.8	3460	A	24.6	3570	D	19.4	2810	A
34.4	4990	E	30.9	4480	E	24.3	3520	E	25.2	3650	B	19.7	2860	E
34.5	5010	B	31.5	4570	B	24.7	3580	E	25.3	3670	E	20.0	2900	E
37.3	5420	B	32.6	4730	B	25.5	3700	B	26.1	3790	E	21.2	3070	E
37.6	5450	B	32.9	4770	B	25.9	3750	B	26.8	3880	E	21.5	3120	B
37.8	5480	A	34.1	4950	B	25.9	3760	E	27.1	3930	B	21.9	3170	A
37.9	5500	A	37.0	5360	A	26.1	3780	E	33.5	4860	A	22.7	3290	A
38.1	5520	A	37.0	5370	A	26.3	3810	B	33.9	4910	A	22.8	3300	B
38.3	5550	A	37.0	5380	A	34.7	5030	C	35.1	5090	A	24.1	3500	B
39.0	5650	B	38.2	5540	A	34.8	5040	C	35.8	5200	A	25.2	3660	B
						37.2	5400	C						
						37.7	5470	C						

Table 6

Use of Wilcoxon sum of ranks test to determine if samples from company B significantly differ after 1000 hour aging. 6061T-6 - Reliabond 7114 - FPL etch

Data values		Tally		Rank value		A ranks	B ranks
MPa	psi						
10.6	1540	A		1	18		
11.4	1660	A		2	17		
11.9	1730	A		3	16		
12.1	1760	A		4	15		
14.0	2030	A		5	14		
14.5	2100	A		6	13		
15.4	2230	A		7	12		
15.6	2260	A		8	11		
19.4	2810	A		9	10		
19.7	2860	A		10	9		
20.0	2900	A		11	8		
21.2	3070	A		12	7		
21.5	3120		B	13	6		6
21.9	3170	A		14	5		
22.7	3290	A		15	4		
22.8	3300		B	16	3		3
24.1	3500		B	17	2		2
25.2	3660		B	18	1		1
							R = 12

P 1% Significant difference for B

Table 7

R tables for the Wilcoxon sum of ranks test*

n_A	n_B	P = 10%	P = 5%	P = 1%	P = 0.2%	n_A	n_B	P = 10%	P = 5%	P = 1%	P = 0.2%
2	8	4	3	--	--	4	10	17	15	12	10
2	9	4	3	--	--	4	11	18	16	12	10
2	10	4	3	--	--	4	12	19	17	13	10
2	11	4	3	--	--	4	13	20	18	13	11
2	12	5	4	--	--	4	14	21	19	14	11
2	13	5	4	--	--	4	15	22	20	15	11
2	14	6	4	--	--	4	16	24	21	15	12
2	15	6	4	--	--	4	17	25	21	16	12
2	16	6	4	--	--	4	18	26	22	16	13
2	17	6	5	--	--	4	19	27	23	17	13
2	18	7	5	--	--	4	20	28	24	18	13
2	19	7	5	3	--	5	5	19	17	15	--
2	20	7	5	3	--	5	6	20	18	16	--
3	5	7	6	--	--	5	7	21	20	16	--
3	6	8	7	--	--	5	8	23	21	17	15
3	7	8	7	--	--	5	9	24	22	18	16
3	8	9	8	--	--	5	10	26	23	19	16
3	9	10	8	6	--	5	11	27	24	20	17
3	10	10	9	6	--	5	12	28	26	21	17
3	11	11	9	6	--	5	13	30	27	22	18
3	12	11	10	7	--	5	14	31	28	22	18
3	13	12	10	7	--	5	15	33	29	23	19
3	14	13	11	7	--	5	16	34	30	24	20
3	15	13	11	8	--	5	17	35	32	25	20
3	16	14	12	8	--	5	18	37	33	26	21
3	17	15	12	8	6	5	19	38	34	27	22
3	18	15	13	8	6	5	20	40	35	28	22
3	19	16	13	9	6	6	6	28	26	23	--
3	20	17	14	9	6	6	7	29	27	24	21
4	4	11	10	--	--	6	8	31	29	25	22
4	5	12	11	--	--	6	9	33	31	26	23
4	6	13	12	10	--	6	10	35	32	27	24
4	7	14	13	10	--	6	11	37	34	28	25
4	8	15	14	11	--	6	12	38	35	30	25
4	9	16	14	11	--	6	13	40	37	31	26

Table 7 - Continued*

n_A	n_B	P = 10%	P = 5%	P = 1%	P = 0.2%	n_A	n_B	P = 10%	P = 5%	P = 1%	P = 0.2%
6	14	42	38	32	27	9	12	75	71	63	57
6	15	44	40	33	28	9	13	78	73	65	59
6	16	46	42	34	29	9	14	81	76	67	60
6	17	47	43	36	30	9	15	84	79	69	62
6	18	49	45	37	31	9	16	87	82	72	64
6	19	51	46	38	32	9	17	90	84	74	66
6	20	53	48	39	33	9	18	93	87	76	68
7	7	39	36	32	29	9	19	96	90	78	70
7	8	41	38	34	30	9	20	99	93	81	71
7	9	43	40	35	31	10	10	82	78	71	65
7	10	45	42	37	33	10	11	86	81	73	67
7	11	47	44	38	34	10	12	89	84	76	69
7	12	49	46	40	35	10	13	92	88	79	72
7	13	52	48	41	36	10	14	96	91	81	74
7	14	54	50	43	37	10	15	99	94	84	76
7	15	56	52	44	38	10	16	103	97	86	78
7	16	58	54	46	39	10	17	106	100	89	80
7	17	61	56	47	41	10	18	110	103	92	82
7	18	63	58	49	42	10	19	113	107	94	84
7	19	65	60	50	43	10	20	117	110	97	87
7	20	67	62	52	44	11	11	100	96	87	81
8	8	51	49	43	40	11	12	104	99	90	83
8	9	54	51	45	41	11	13	108	103	93	86
8	10	56	53	47	42	11	14	112	106	96	88
8	11	59	55	49	44	11	15	116	110	99	90
8	12	62	58	51	45	11	16	120	113	102	93
8	13	64	60	53	47	11	17	123	117	105	95
8	14	67	62	54	48	11	18	127	121	108	98
8	15	69	65	56	50	11	19	131	124	111	100
8	16	72	67	58	51	11	20	135	128	114	103
8	17	75	70	60	53	12	12	120	115	105	98
8	18	77	72	62	54	12	13	125	119	109	101
8	19	80	74	64	56	12	14	129	123	112	103
8	20	83	77	66	57	12	15	133	127	115	106
9	9	66	62	56	52	12	16	138	131	119	109
9	10	69	65	58	53	12	17	142	135	122	112
9	11	72	68	61	55	12	18	146	139	125	115

Table 7 - Continued*

n_A	n_B	P = 10%	P = 5%	P = 1%	P = 0.2%	n_A	n_B	P = 10%	P = 5%	P = 1%	P = 0.2%
12	19	150	143	129	118	15	17	203	195	180	167
12	20	155	147	132	120	15	18	208	200	184	171
13	13	142	136	125	117	15	19	214	205	189	175
13	14	147	141	129	120	15	20	220	210	193	179
13	15	152	145	133	123	16	16	219	211	196	184
13	16	156	150	136	126	16	17	225	217	201	188
13	17	161	154	140	129	16	18	231	222	206	192
13	18	166	158	144	133	16	19	237	228	210	196
13	19	171	163	148	136	16	20	243	234	215	201
13	20	175	167	151	139	17	17	249	240	223	210
14	14	166	160	147	137	17	18	255	246	228	214
14	15	171	164	151	141	17	19	262	252	234	219
14	16	176	169	155	144	17	20	268	258	239	223
14	17	182	174	159	148	18	18	280	270	252	237
14	18	187	179	163	151	18	19	287	277	258	242
14	19	192	183	168	155	18	20	294	283	263	247
14	20	197	188	172	159	19	19	313	303	283	267
15	15	192	184	171	160	19	20	320	309	289	272
15	16	197	190	175	163	20	20	348	337	315	298

*These tables have been adapted from S. Siegel and J. Tukey, Journ. Amer. Statist. Assoc., 1960, pp. 434-40, with corrections from D. B. Owen, Handbook of Statistical Tables, #11.5 (Addison-Wesley, 1962).

Table 8

Use of Wilcoxon sum of ranks test to determine if samples from company B significantly differ
90°C (200°F) 5052H34/Reliabond 7114 - FPL etch

Data values			Tally		Rank value	A ranks	B ranks
MPa	psi	Co.					
17.0	2460	D	A		20		
17.8	2580	C	A		19		
18.5	2680	C	A		18		
18.8	2720	C	A		17		
19.0	2760	C	A		16		
20.4	2960	D	A		15		
21.7	3140	E	A		14		
21.9	3170	D	A		13		
22.2	3220	E	A		12		
22.8	3310	D	A		11		
23.1	3350	B		B	10		10
23.2	3360	A B E	A A	B	7,8,9 = 8		8
23.4	2400	B E	A	B	5,6 = 5.5		5.5
23.6	3430	B		B	4		4
24.3	3520	A	A		3		
24.4	3540	A	A		2		
24.5	3560	A	A		1		
							R = 27.5

P 10% No significant difference for B

Table 9

Data for 5052H34 using FPL etch

(73°F) 23°C			(140°F) 60°C			(200°F) 93°C			100 Hr aging			1000 Hr aging		
MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.
20.3	2950	D	17.4	2530	C	17.0	2460	D	15.9	2310	C	8.5	1230	C
22.5	3270	D	18.1	2620	C	17.8	2580	C	16.8	2430	C	10.1	1460	C
23.1	3350	C	18.9	2740	C	18.5	2680	C	17.0	2470	C	10.2	1480	C
23.3	3380	D	21.7	3140	D	18.8	2720	C	17.2	2490	C	10.2	1480	C
25.7	3725	C	22.0	3190	D	19.0	2760	C	20.1	2920	D	12.0	1740	D
25.9	3750	C	22.0	3190	C	20.4	2960	D	20.2	2930	D	13.4	1940	D
26.4	3830	D	23.8	3450	D	21.7	3140	E	20.8	3010	D	14.0	2030	D
28.5	4130	B	25.5	3700	D	21.9	3170	D	21.1	3060	D	15.0	2180	D
29.0	4210	B	27.6	4010	B	22.2	3220	E	23.1	3350	E	17.2	2490	B
29.2	4230	B	27.9	4040	B	22.8	3310	D	25.5	3700	E	20.0	2900	E
29.4	4270	B	28.0	4060	B	23.1	3350	B	25.9	3760	E	21.4	3100	E
31.5	4570	E	28.3	4100	B	23.2	3360	E	26.8	3880	E	22.3	3240	B
31.6	4580	E	30.8	4470	E	23.2	3360	A	27.5	3990	B	22.4	3250	E
31.9	4620	E	30.8	4470	A	23.2	3360	B	28.3	4100	B	23.1	3350	B
31.9	4630	A	31.0	4490	E	23.4	3400	B	28.4	4120	B	23.9	3460	E
32.4	4700	E	31.1	4510	A	23.4	3400	E	28.8	4180	B	24.0	3480	B
32.7	4740	A	31.1	4510	E	23.6	3430	B	31.0	4500	A	28.5	4130	A
32.9	4770	A	31.4	4550	E	24.3	3520	A	31.5	4570	A	29.0	4200	A
33.2	4820	A	32.5	4720	A	24.4	3540	A	31.6	4580	A	29.0	4200	A
			32.5	4720	A	24.5	3560	A	31.7	4600	A	29.4	4260	A

Table 10

Data for 6061T-6 using BR127 primer

(73°F) 23°C			(140°F) 60°C			(200°F) 93°C			100 Hr aging			1000 Hr aging		
MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.
25.9	3750	C	19.9	2880	B	19.3	2800	B	15.0	2180	D	14.0	2030	D
27.5	3990	D	20.7	3000	B	20.2	2930	B	15.4	2240	D	14.8	2150	D
27.9	4040	D	25.7	3730	C	20.7	3000	B	15.9	2300	D	15.2	2210	D
28.2	4090	C	28.0	4060	B	21.5	3120	B	16.7	2420	D	16.3	2370	D
28.5	4140	D	28.1	4070	C	22.3	3240	D	17.5	2540	C	17.6	2550	C
29.3	4250	D	28.3	4100	C	22.9	3320	D	18.5	2680	B	18.8	2720	C
29.4	4270	C	28.6	4150	D	23.0	3340	D	18.7	2960	B	19.1	2770	B
31.4	4560	B	30.1	4360	D	23.2	3370	D	20.4	2710	C	19.4	2810	B
31.7	4600	B	30.3	4390	D	23.4	3400	C	21.1	3060	C	19.9	2880	B
32.2	4670	B	31.0	4490	D	23.7	3440	C	21.1	3060	C	20.5	2970	B
33.0	4780	B	31.0	4500	C	24.1	3500	A	23.0	3330	B	21.2	3080	C
34.1	4950	C	31.8	4610	B	24.7	3580	E	25.4	3690	B	22.4	3250	A
35.0	5080	E	32.7	4740	E	24.9	3610	A	29.1	4220	E	24.2	3510	A
35.2	5100	A	33.5	4860	E	25.2	3660	A	31.6	4580	E	24.8	3600	C
35.6	5160	A	35.3	5120	E	26.1	3780	E	32.5	4720	E	25.0	3620	A
35.6	5160	E	35.3	5120	A	26.2	3800	A	32.6	4730	E	26.2	3800	A
35.8	5190	A	35.8	5190	E	27.0	3920	E	34.6	5020	A	27.9	4050	E
36.5	5300	A	38.1	5520	A	27.3	3960	C	34.9	5060	A	28.1	4080	E
37.1	5380	E	38.2	5540	A	27.5	3990	E	35.9	5210	A	28.2	4090	E
37.6	5460	E	38.4	5570	A	27.6	4000	C	36.1	5230	A	29.2	4240	E

Table 11

Data for 5052H34 using BR127 primer

(73°F) 23°C			(140°F) 60°C			(200°F) 93°C			100 Hr aging			1000 Hr aging		
MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.	MPa	psi	Co.
18.4	2670	D	21.0	3040	D	13.9	2020	D	14.8	2140	D	13.8	1980	D
19.6	2840	C	22.3	3240	D	15.9	2310	D	15.7	2270	D	15.1	2190	D
19.6	2840	D	22.4	3250	D	17.9	2590	D	16.2	2350	C	15.2	2200	D
21.4	3100	C	23.4	3400	C	20.5	2980	B	16.3	2370	D	15.4	2240	C
21.4	3100	C	24.0	3480	B	20.6	2990	D	16.5	2400	C	15.8	2290	C
21.4	3110	D	24.8	3600	B	20.8	3020	B	17.3	2510	C	16.1	2340	D
23.0	3340	C	25.4	3680	D	21.0	3050	B	17.8	2580	D	16.1	2340	C
24.3	3530	D	25.4	3690	C	21.5	3120	B	17.9	2600	C	17.8	2580	C
25.9	3760	B	26.1	3790	B	22.3	3230	E	26.9	3900	B	21.1	3060	B
26.2	3800	B	26.5	3840	B	22.3	3240	E	27.4	3970	B	23.3	3380	B
27.0	3920	B	28.3	4110	C	23.2	3360	A	27.8	4030	B	24.1	3490	E
27.4	3970	B	30.6	4440	E	24.3	3520	A	28.0	4060	E	24.3	3520	B
27.9	4050	A	31.2	4520	A	24.4	3540	A	28.1	4080	E	25.2	3650	B
30.8	4460	E	31.2	4530	C	24.5	3560	A	28.5	4130	B	25.9	3750	A
30.8	4470	A	31.3	4540	A	25.0	3630	C	28.6	4150	E	26.5	3850	E
30.8	4470	A	31.4	4550	E	25.0	3630	E	29.2	4230	E	26.8	3880	E
31.2	4520	E	31.4	4560	E	25.6	3710	E	30.2	4380	A	26.8	3890	E
31.3	4540	E	31.4	4560	A	26.6	3860	C	30.8	4470	A	27.1	3930	A
31.4	4560	A	32.0	4640	A	27.8	4030	C	31.3	4540	A	27.2	3940	A
32.1	4650	E	32.2	4670	E	27.8	4030	C	31.4	4550	A	27.2	3950	A

Table 12

Comparison of 6061T-6/FPL etch bonds by company

Test Condition	Company A	B	C	D	E
(73°F) 23°C	High 3	Avg 2	Low 1	Avg 2	Avg 2
(140°F) 60°C	High 3	Avg 2	Low 1	Avg 2	Avg 2
(200°F) 93°C	Avg 2	Avg 2	High 3	Low 1	Avg 2
100 Hr	High 3	Avg 2	Low 1	Avg 2	Avg 2
1000 Hr	Avg 2	High 3	Avg 2	Low 1	Avg 2
Point total	13	11	8	8	10

Table 13

Comparison of 6061T-6/BR127 primer bonds by company

Test Condition	Company A	B	C	D	E
(73°F) 23°C	High 3	Avg 2	Avg 2	Low 1	High 3
(140°F) 60°C	High 3	Low 1	Avg 2	Avg 2	Avg 2
(200°F) 93°C	Avg 2	Low 1	Avg 2	Avg 2	Avg 2
100 Hr	High 3	Avg 2	Avg 2	Low 1	Avg 2
1000 Hr	Avg 2	Avg 2	Avg 2	Low 1	High 3
Point total	13	8	10	7	12

Table 14

Comparison of 5052H34/FPL etch bonds by company

Test Condition	Company A	B	C	D	E
(73°F) 23°C	High 3	Avg 2	Avg 2	Low 1	Avg 2
(140°F) 60°C	High 3	Avg 2	Low 1	Avg 2	Avg 2
(200°F) 93°C	High 3	Avg 2	Low 1	Avg 2	Avg 2
100 Hr	High 3	Avg 2	Low 1	Avg 2	Avg 2
1000 Hr	High 3	Avg 2	Low 1	Avg 2	Avg 2
Point total	15	10	6	9	10

Table 15

Comparison of 5052H34/BR127 primer bonds by company

Test Condition	Company A	B	C	D	E
(73°F) 23°C	Avg 2	Avg 2	Low 1	Low 1	High 3
(140°F) 60°C	High 3	Avg 2	Avg 2	Low 1	High 3
(200°F) 93°C	Avg 2	Avg 2	High 3	Low 1	Avg 2
100 Hr	High 3	Avg 2	Avg 2	Low 1	Avg 2
1000 Hr	High 3	Avg 2	Avg 2	Low 1	Avg 2
Point total	13	10	10	5	12

Table 16

Company point totals

System and Treatment	Company A	B	C	D	E
6061T-6 FPL	13	11	8	8	10
5052H34 FPL	15	10	6	9	10
6061T-6 BR127 primer	13	8	10	7	12
5052H34 BR127 primer	13	10	10	5	12
Grand total	54	39	34	29	44

Table 17

Kruskal and Wallis test for C at 23°C (73°F) - 6061T-6

x = FPL
y = BR127
z = FM47

$n_A = 3$
$n_B = 4$
$n_C = 3$

Data values			Tally	Rank values	A Ranks	B Ranks	C Ranks
MPa	psi						
25.9	3750	(y)	B	1		1	
27.2	3940	(x)	A	2	2		
27.5	3990	(z)	C	3			3
27.6	4010	(x)	A	4	4		
27.7	4020	(x)	A	5	5		
28.2	4090	(z)	C	6			6
28.9	4190	(y)	B	7		7	
29.4	4270	(z)	C	8			8
32.1	4650	(y)	B	9		9	
34.1	4950	(y)	B	10		10	
					$R_A = 11$	$R_B + 27$	$R_C = 17$
					$n_A = 3$	$n_B = 4$	$n_C = 3$

P 10% No significant difference

Table 18

X^2 table for Kruskal and Wallis test*

No. in each group			Minimal values of K. and W.'s indicating		
n_A	n_B	n_C	P = 10%	P = 5%	P = 1%
1	2	5	4.2	5.0	---
1	3	3	4.6	5.1	---
1	3	4	4.0	5.2	---
1	3	5	4.0	4.9	6.5
1	4	4	4.1	4.9	6.67
1	4	5	4.0	4.9	6.9
1	5	5	4.1	5.0	7.1
2	2	3	4.5	4.7	---
2	2	4	4.5	5.1	---
2	2	5	4.3	5.1	6.4
2	3	3	4.6	5.2	6.3
2	3	4	4.5	5.4	6.35
2	3	5	4.5	5.2	6.82
2	4	4	4.5	5.3	6.9
2	4	5	4.5	5.3	7.12
2	5	5	4.5	5.3	7.3
3	3	3	4.6	5.6	6.5
3	3	4	4.7	5.7	6.75
3	3	5	4.5	5.6	7.0
3	4	4	4.5	5.6	7.14
3	4	5	4.5	5.6	7.44
3	5	5	4.5	5.6	7.55
4	4	4	4.6	5.7	7.6
4	4	5	4.6	5.6	7.75
4	5	5	4.5	5.6	7.8
5	5	5	4.6	5.7	7.98

*Adapted from W. H. Kruskal and W. A. Wallis, Journ. Amer. Statist. Assoc., 1952, pp. 614-17 and 1953, 1. 910.

Table 19

Kruskal and Wallis test for C after 1000 hrs aging - 6061T-6

x = FPL n_A
y = BR127 n_B
z = FM47 n_C

Data values MPa	psi		Tally	Rank values	A Ranks	B Ranks	C Ranks
14.0	2030	(x)	A	1	1		
14.5	2100	(x)	A	2	2		
15.4	2230	(x)	A B	3	3		
17.6	2550	(y)	B	4		4	
18.8	2720	(y)	C	5		5	
21.0	3040	(z)	B	6			6
21.2	3080	(y)	C	7		7	
21.5	3120	(z)	C	8			8
22.5	3260	(z)	B	9			9
24.8	3600	((y)		10		10	
					$R_A = 6$	$R_B = 26$	$R_C = 23$
			N = 10		$n_A = 3$	$n_B = 4$	$n_C = 3$

P 5% significant difference

Table 20

K table for selected comparisons*

Total number of samples in experiment K	Values of K indicating P = 5%	P = 1%
3	2.89	3.60
4	4.22	5.12
5	5.60	6.69
6	7.01	8.30
7	8.46	9.92
8	9.94	11.58
9	11.43	13.25
10	12.97	14.95

*Adapted from reference 1.

Table 21

Comparison of FPL with primers by the Kruskal and Wallis test

Test condition	C		E	
	5052H34	6061T-6	5052H34	6061T-6
(73°F) 23°C	FPL intermediate	Average	Average	FPL low
(140°F) 60°C	FPL low	Average	Average	FPL low
(200°F) 93°C	FPL low	FPL high	FPL low	Average
100 Hrs	FPL low	Average	FPL low	FPL low
1000 Hrs	FPL low	FPL low	FPL low	FPL low

FPL Low $\frac{12}{20} \times 100 = 60\%$ of the tests

Average $\frac{6}{20} \times 100 = 30\%$ of the tests

Intermediate $\frac{1}{20} \times 100 = 5\%$ of the tests

FPL High $\frac{1}{20} \times 100 = 5\%$ of the tests

Table 22

Comparison of FPL and primers for combined A and E at 93°C (200°F) using Wilcoxon sum of ranks test - 5052H34 aluminum

FPL = A
Primers = B

Data values			Tally		Rank values	A ranks	B ranks
MPa	psi	Co.					
21.7	3140	A	A		1	1	
22.2	3220	A	A		2		
22.3	3230	B		B	3		
22.3	3240	B		B	4		
23.2	3360	A A B	A A	B	5,6,7 = 6	12	
23.4	3400	A	A		8	8	
24.3	3520	A B	A	B	9,10 = 9.5	9.5	
24.4	3540	A B	A	B	11,12 = 11.5	11.5	
24.5	3560	A B	A	B	13,14 = 13.5	13.5	
25.0	3630	B		B	15		
25.6	3710	B		B	16		
26.2	3800	B		B	17		
26.8	3890	B		B	18		
27.0	3910	B		B	19		
27.3	3960	B		B	20		
						$\overline{R = 57.5}$	

P 5% significant difference FPL Low

Table 23

Comparison of FPL and primers for combined A and E at 60°C (140°F) using Wilcoxon sum of ranks test - 5052H34 aluminum

FPL = A
Primers = B

$n_A = 8$
$n_B = 12$

Data values			Tally		Rank values		A Ranks	B Ranks
MPa	psi	Co.						
29.3	4250	B		B	1	20		
29.6	4300	B		B	2	19		
30.4	4410	B		B	3	18		
30.6	4440	B		B	4	17		
30.8	4470	A A	AA		5,6 = 5.5	15, 16	31	
31.0	4490	A	A		7	14	14	
31.1	4510	A A	AA		8,9 = 8.5	12, 13	25	
31.2	4520	B		B	10	11		
31.3	4540	B		B	11	10		
31.4	4550	A B	A	B	12,13 = 12.5	8, 9 - 8.5	8.5	
31.4	4560	B B		BB	14,15 = 14.5	6, 7		
31.8	4610	B		B	16	5		
32.0	4640	B		B	17	4		
32.2	4670	B		B	18	3		
32.5	4720	A A	AA		19,20 = 19.5	2, 1 = 1.5	3	
							R = 81.5	

P 10% No significant difference

Table 24

Comparison of FPL with primers

Test Condition	5052H34 (A, E)	5052H34 (B, C, D)	6061T-6 (A, E)	6061T-6 (B, C, D)
(73°F) 23°C	FPL high	No difference	No difference	No difference
(140°F) 60°C	No difference	No difference	No difference	No difference
(200°F) 93°C	FPL low	No difference	FPL low	No difference
100 Hr	No difference	No difference	No difference	No difference
1000 Hr	No difference	FPL low	FPL low	No difference

FPL low $\frac{4}{20} \times 100 = 20\%$

No difference $\frac{15}{20} \times 100 = 75\%$

FPL high $\frac{1}{20} \times 100 = 5\%$

Table 25

Durability of adhesive bonded 6061T-6 aluminum joints

Company (Adhesive)	Process Primer	Time to failure, hr, Stress, psi (MPa) 500 (3.4)	1000 (6.9)	1500 (10.3)	2000 (13.8)
A	FPL/0			490	200
(7114)	FPL/BR127			380	270
B	FPL/0		230		10
(7114)	FPL/BR127		30		40
C	FPL/0			36	9
(7114)	FPL/BR127	728			1
	FPL/FM47			384	114
D	FPL/0	1390	35		
(7114)	FPL/BR127	2370	2		
E	FPL/0		950		24
(7114)	FPL/BR127		1000		160
	FPL/FM47	240			126

Table 26

Durability of adhesive bonded 5052H34 aluminum joints

Company (Adhesive)	Process Primer	Time to failure, hr Stress, psi (MPa) 500 (3.4)	1000 (6.9)	1500 (10.3)	1760 (12.1)	2000 (13.8)
A	FPL/0			360		110
(7114)	FPL/BR127			300		90
B	FPL/0		900			20
(7114)	FPL/BR127		1000			15
C	FPL/0	8.9			0.4	
(7114)	FPL/BR127	1.5				0.1
	FPL/FM47	15.0		3		
D	FPL/0	110				0.2
(7114)	FPL/BR127		840			10
E	FPL/0			320		70
(9601)	FPL/BR127		700			50
	FPL/FM47			400		145

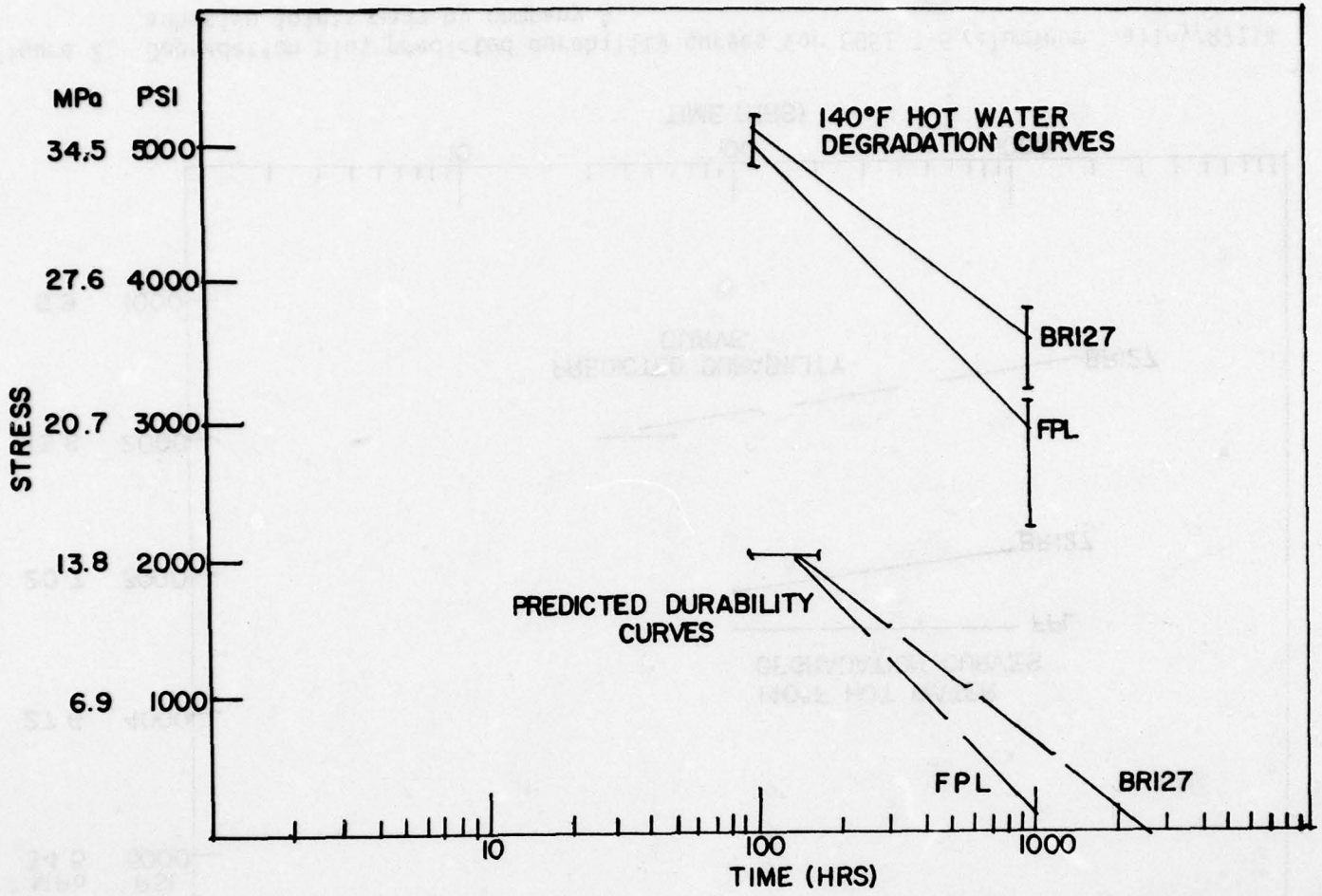


Figure 1. Degradation plus predicted durability curves for 6061 T-6 aluminum alloy/R·7114 adhesive joints made by company A.

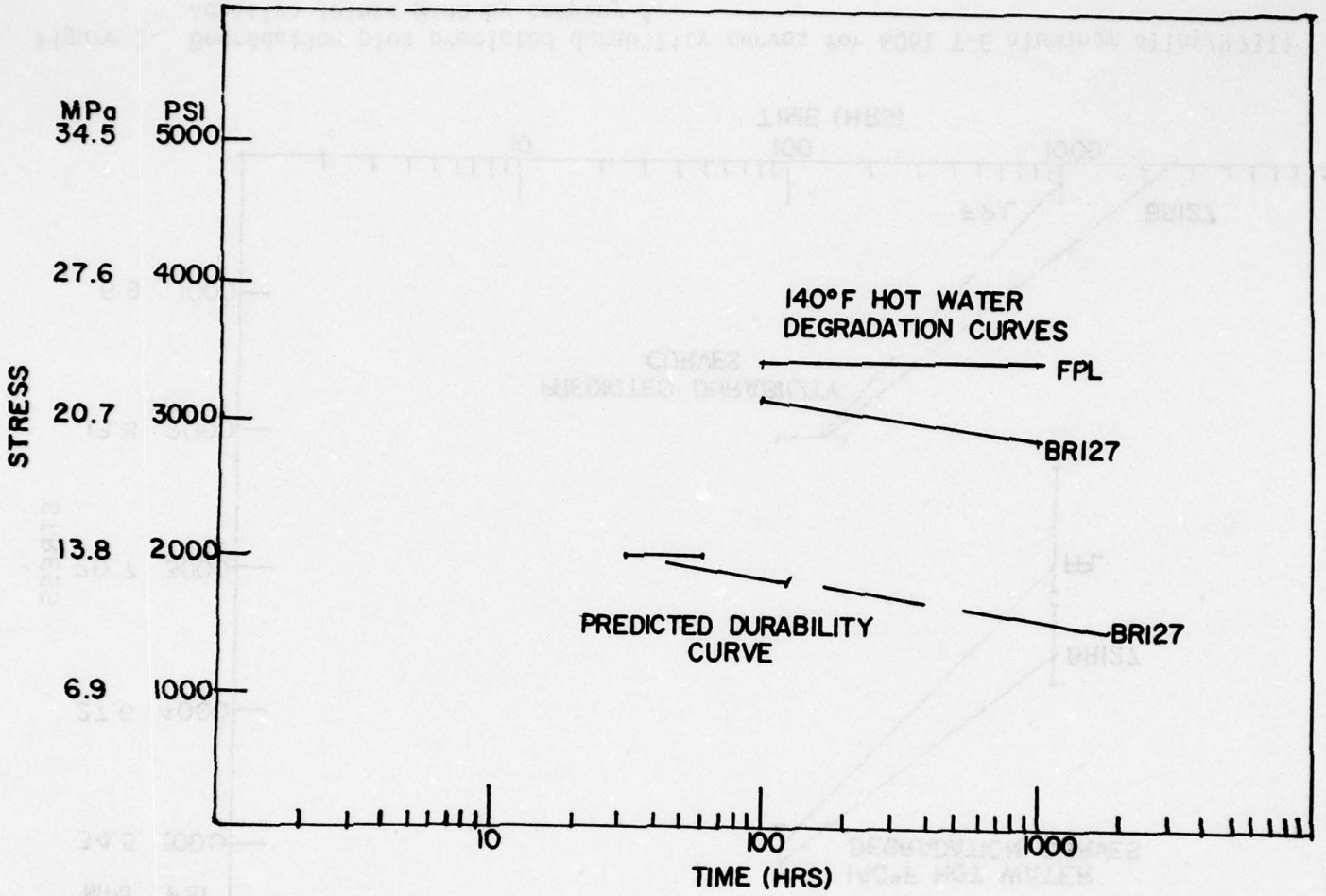


Figure 2. Degradation plus predicted durability curves for 6061 T-6 aluminum alloy/R7114 adhesive joints made by company A.

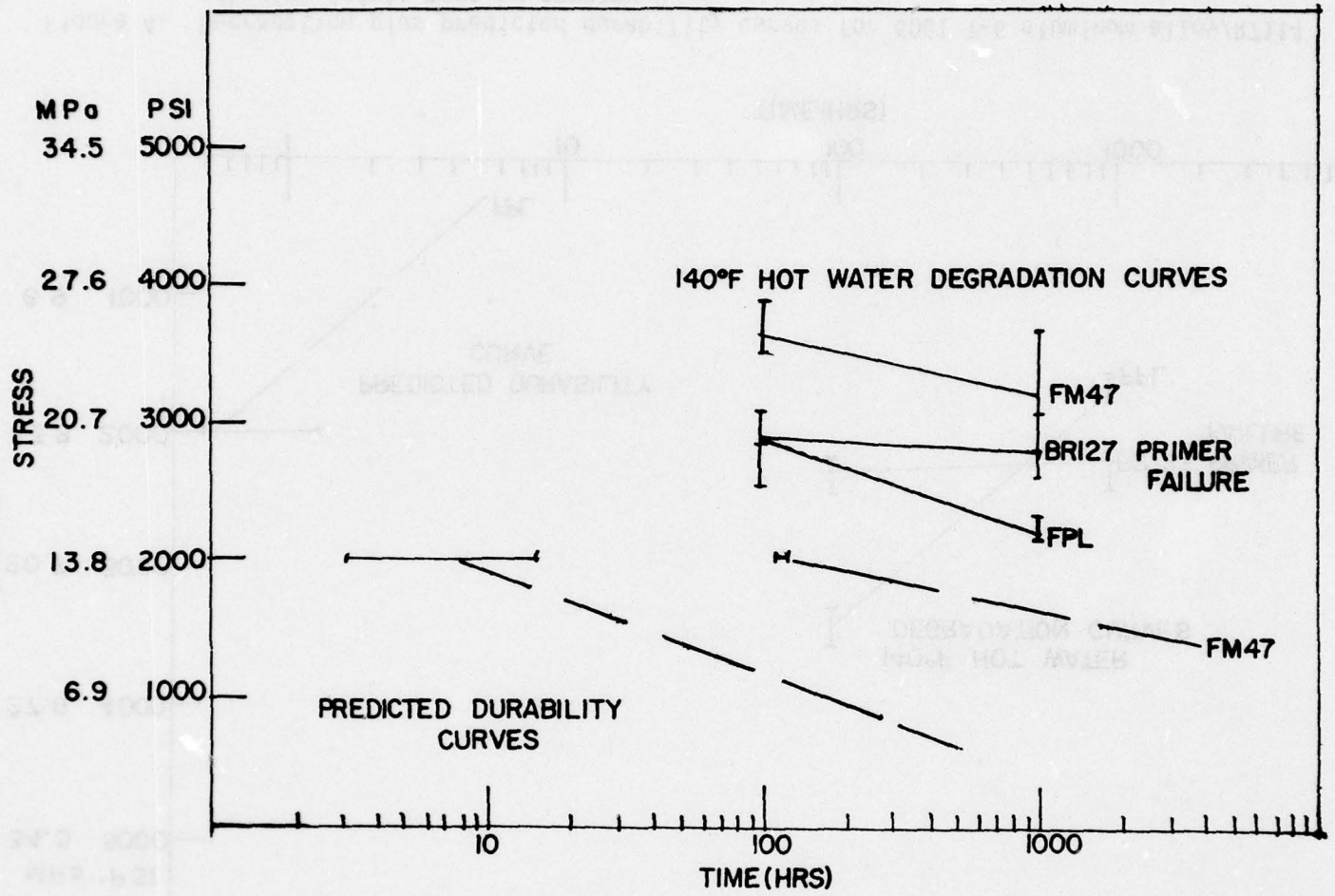


Figure 3. Degradation plus predicted durability curves for 6061 T-6 aluminum alloy/R7114 adhesive joints made by company C.

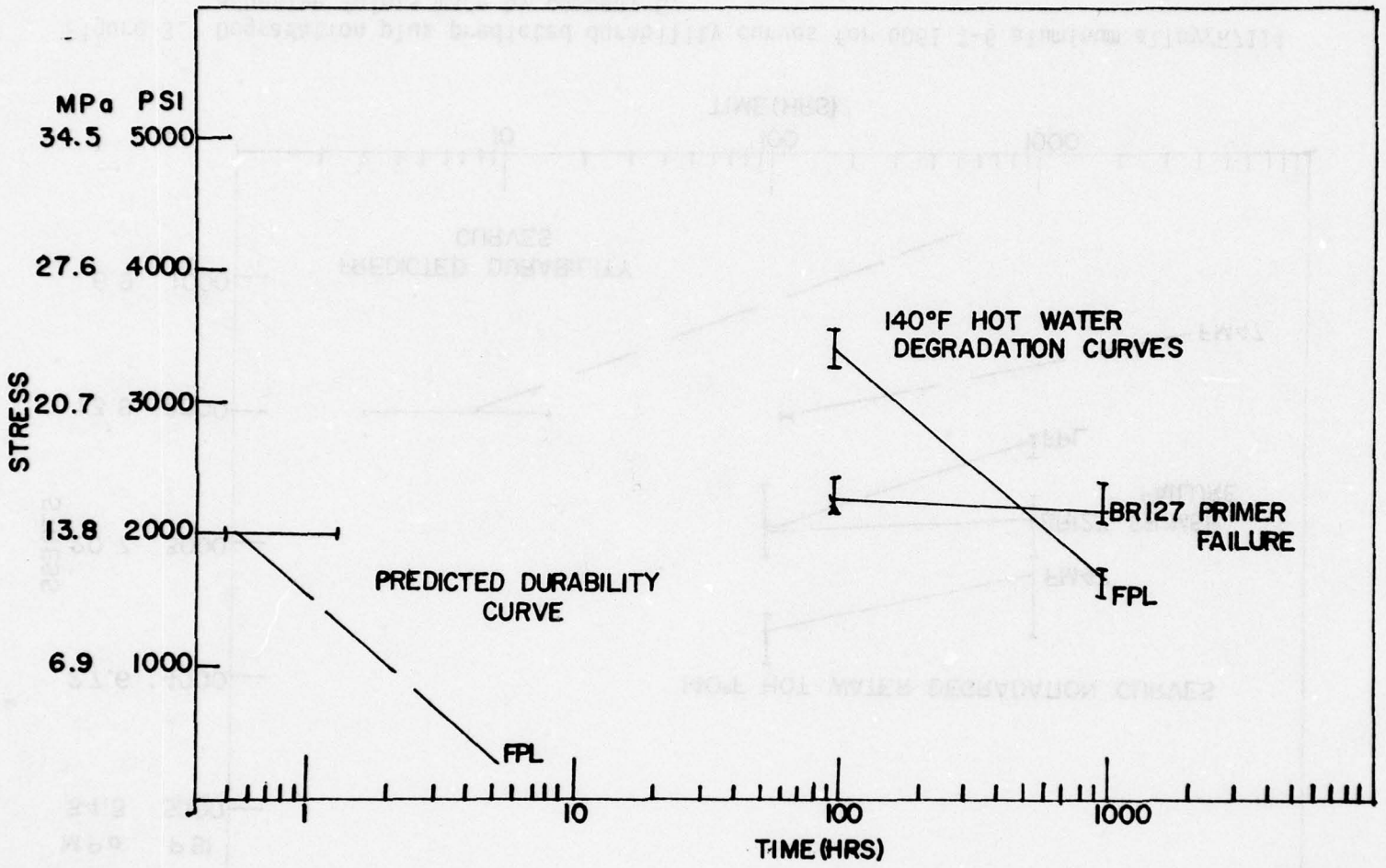


Figure 4. Degradation plus predicted durability curves for 6061 T-6 aluminum alloy/R7114 adhesive joints made by company D.

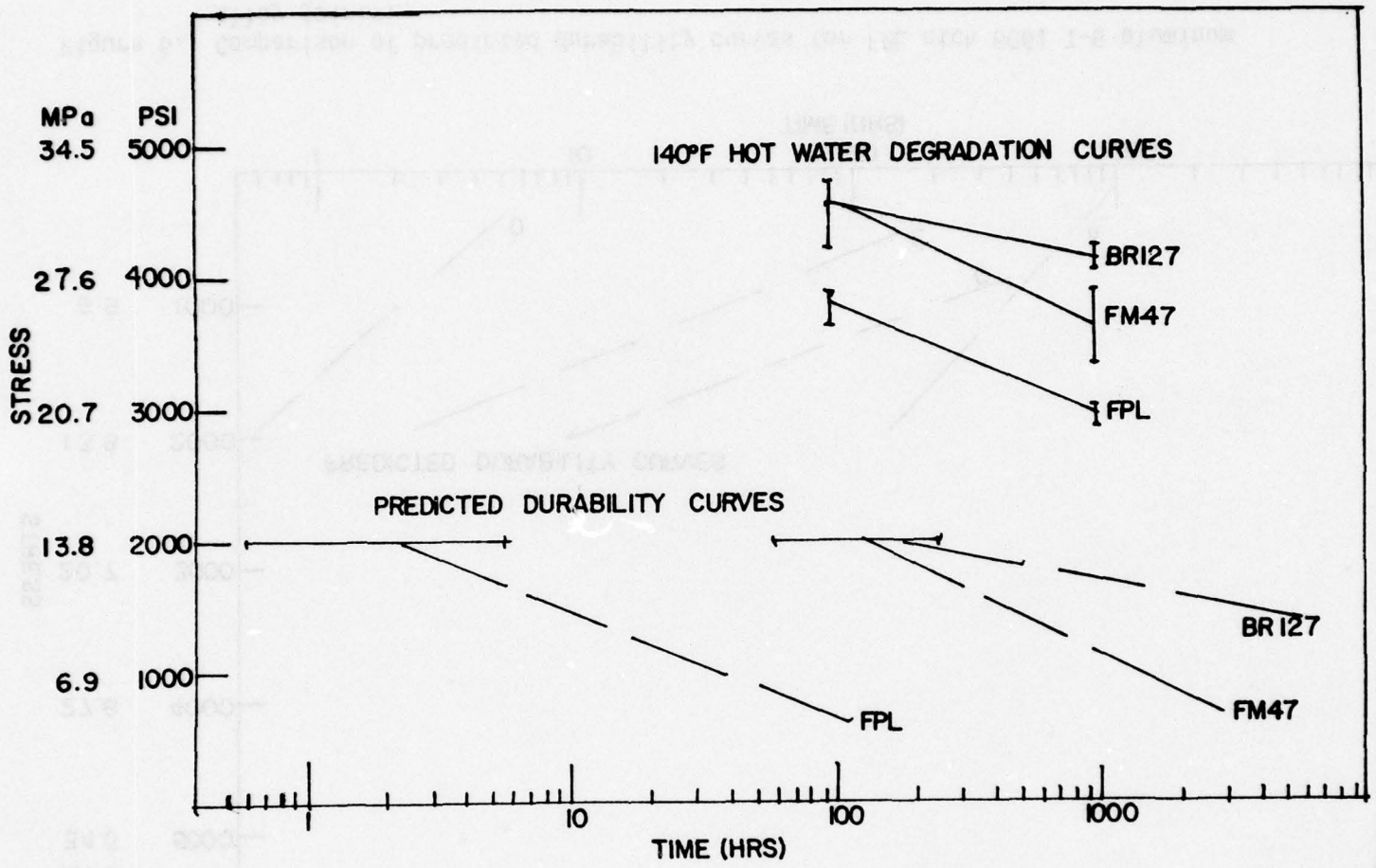


Figure 5. Degradation plus predicted durability curves for 6061 T-6 aluminum alloy/R7114 adhesive joints made by company E.

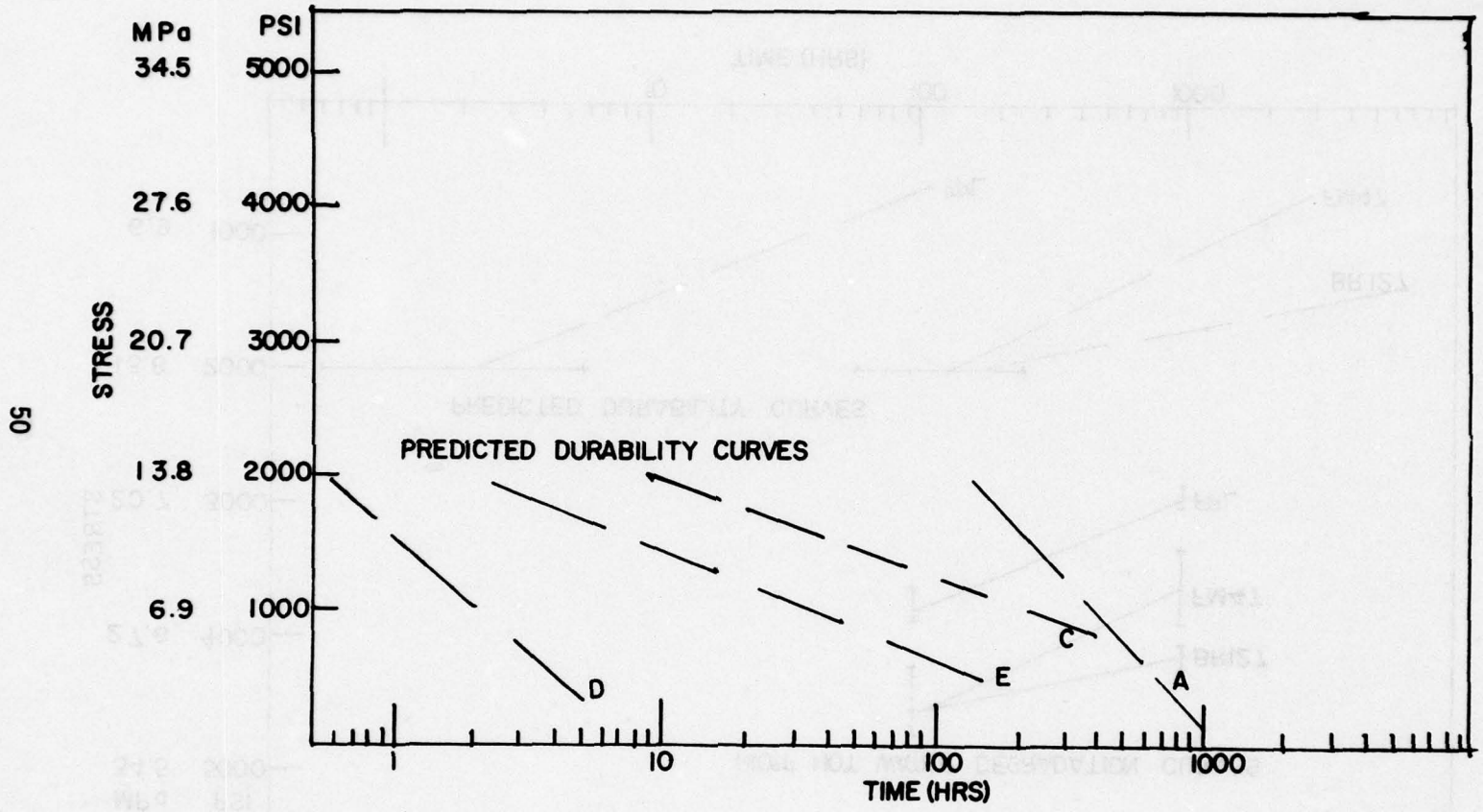


Figure 6. Comparison of predicted durability curves for FPL etch 6061 T-6 aluminum alloy joints.

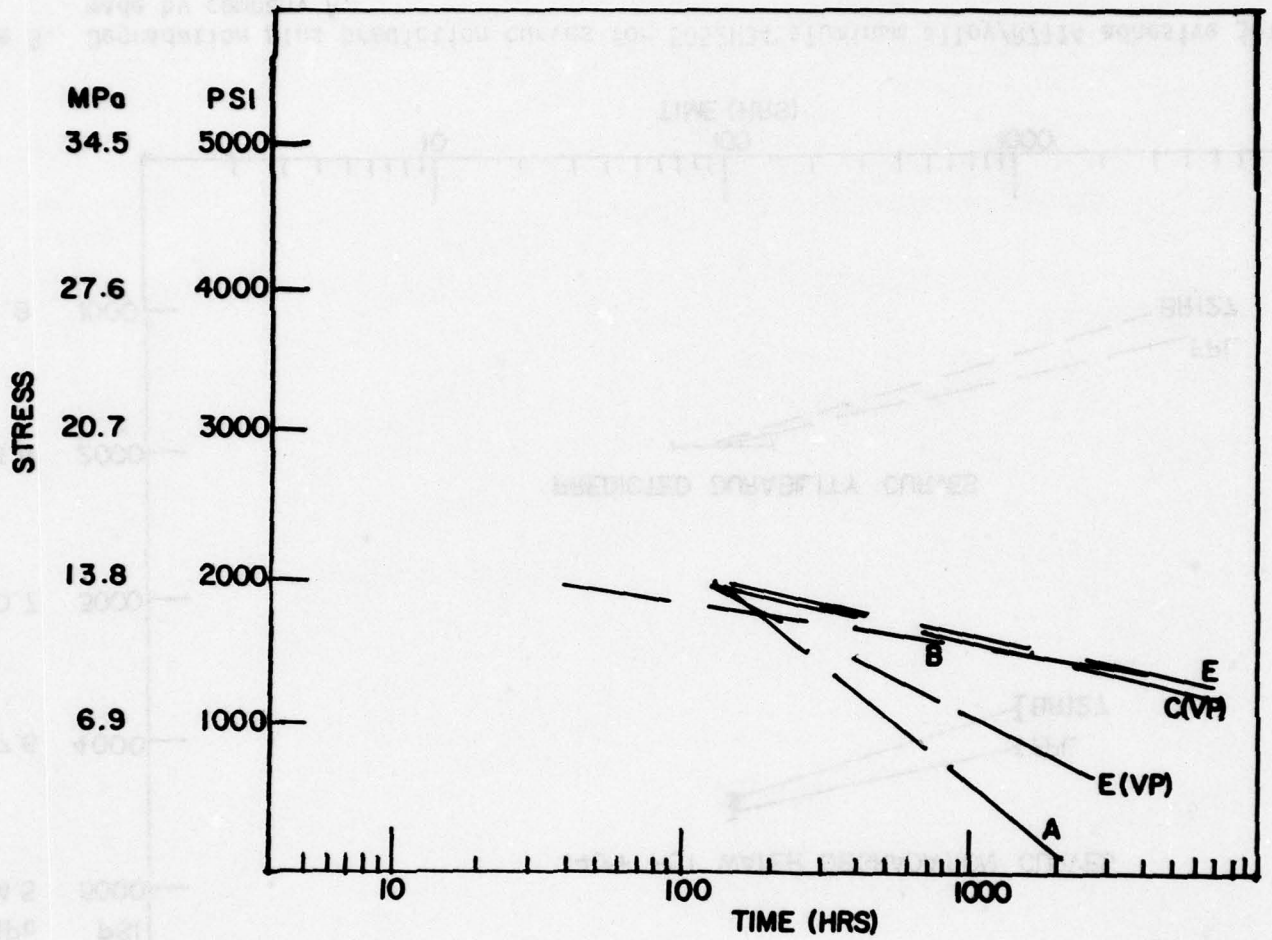


Figure 7. Comparison of predicted durability curves for primed 6061 T-6 aluminum alloy joint.

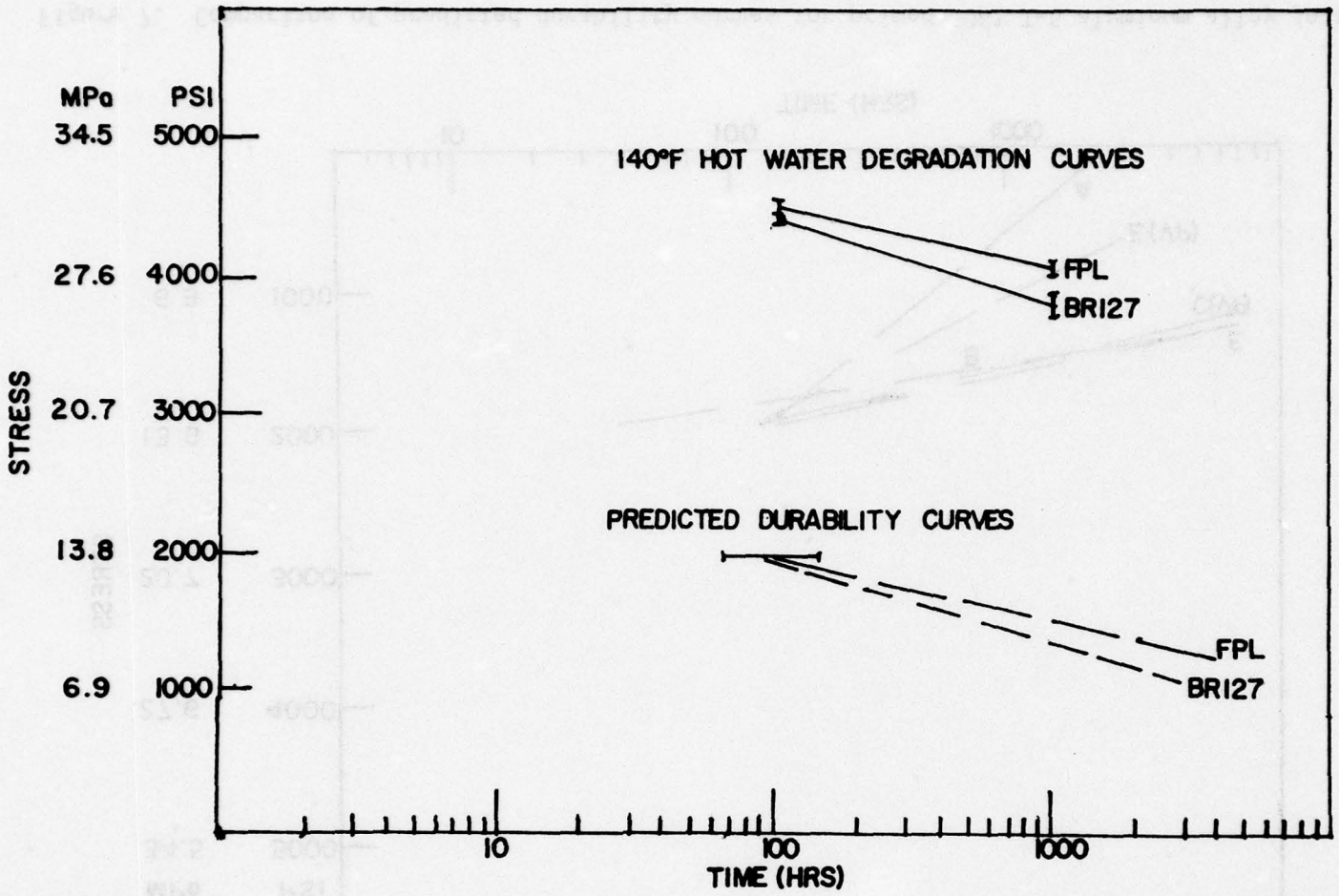


Figure 8. Degradation plus prediction curves for 5052H34 aluminum alloy/R7114 adhesive joints made by company A.

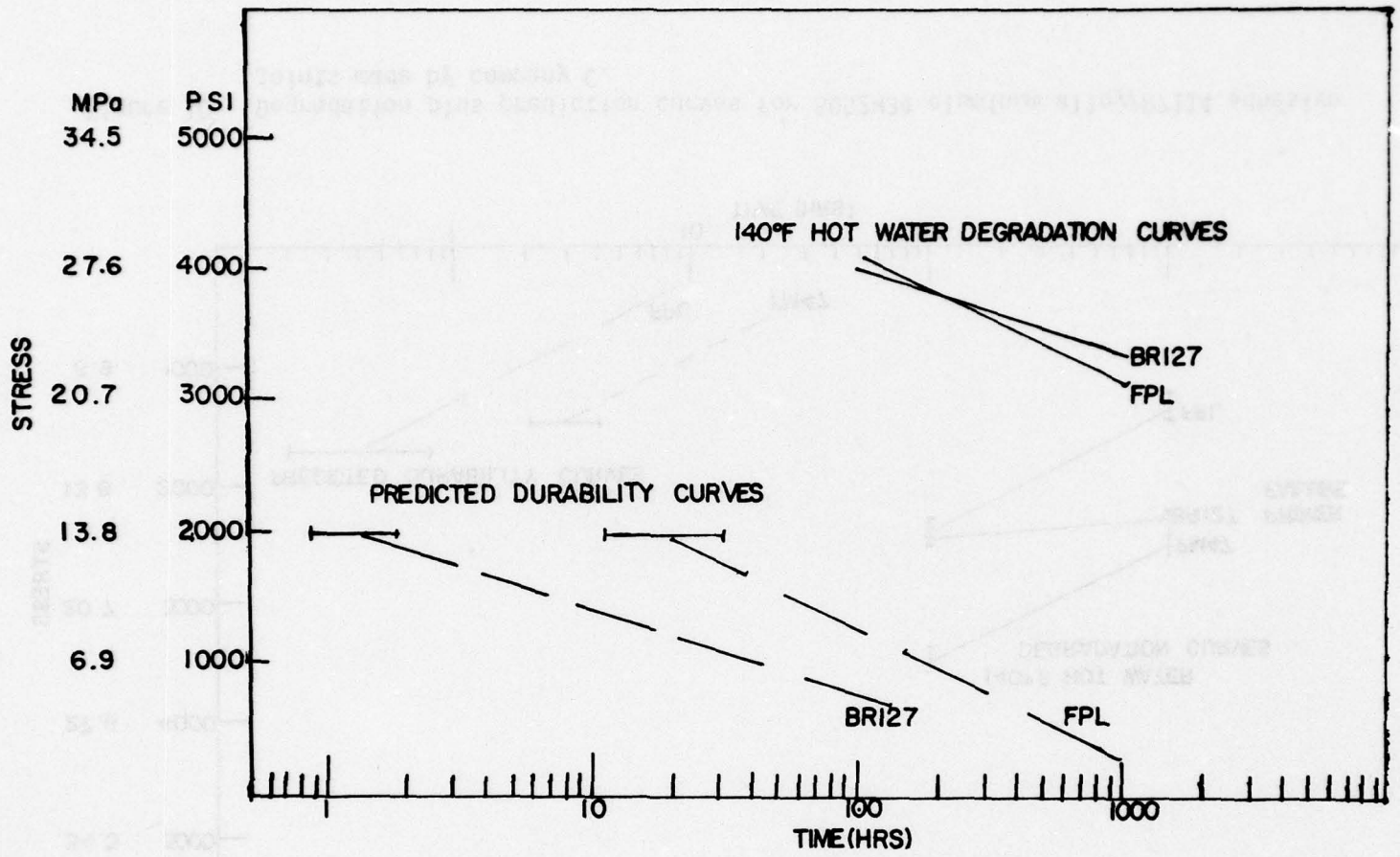


Figure 9. *Degradation plus prediction curves for* 5052H34 aluminum alloy/R7114 adhesive joints made by company B.

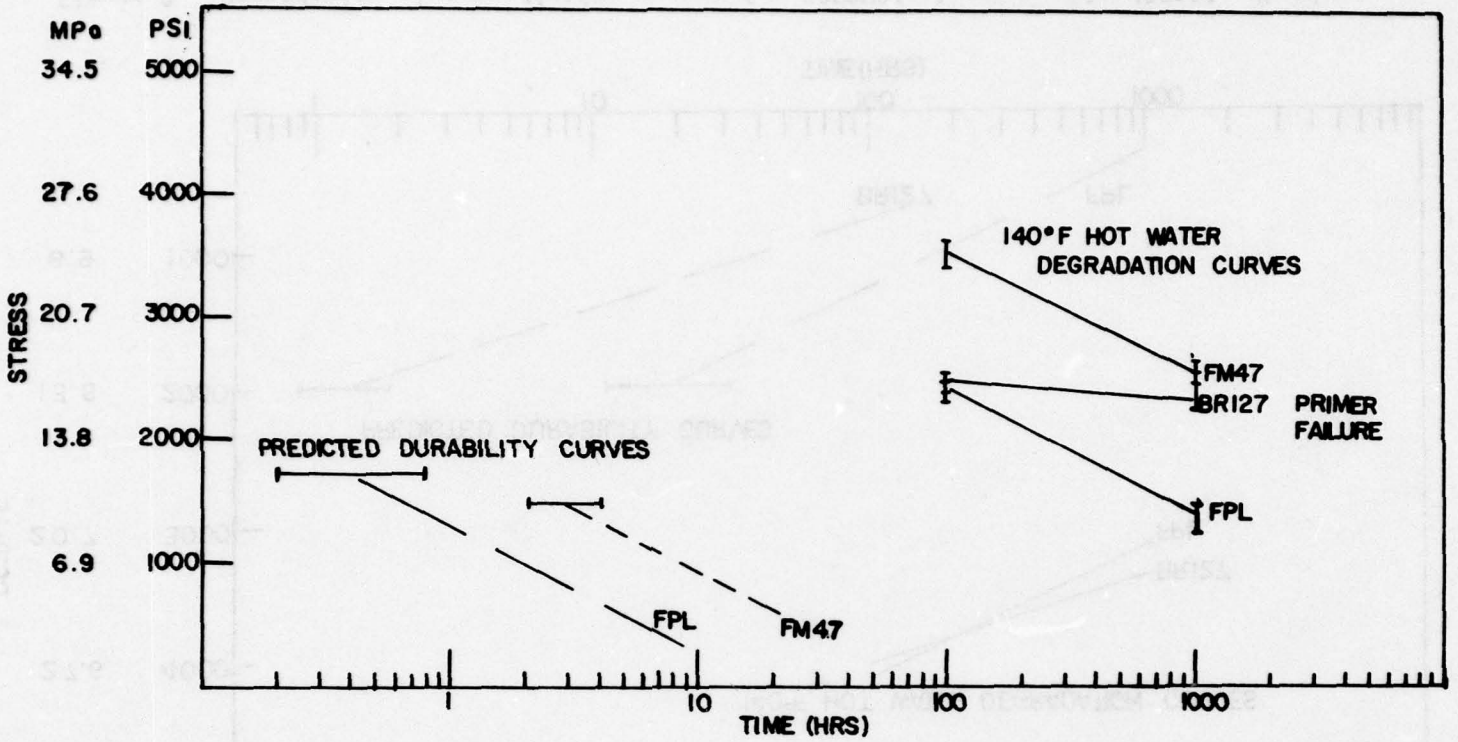


Figure 10. Degradation plus prediction curves for 5052H34 aluminum alloy/R7114 adhesive joints made by company C.

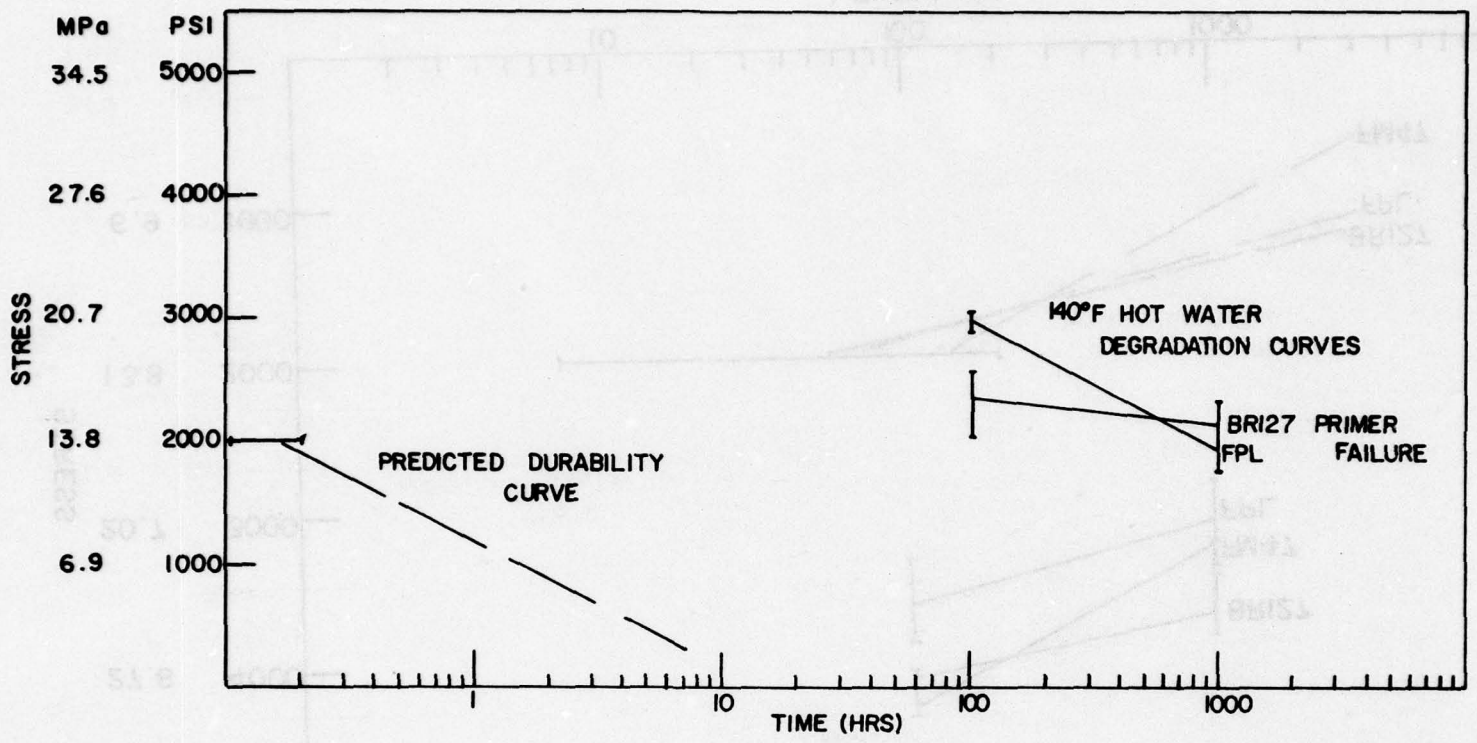


Figure 11. Degradation plus prediction curves for 5052H34 aluminum alloy/R7114 adhesive joints made by company D.

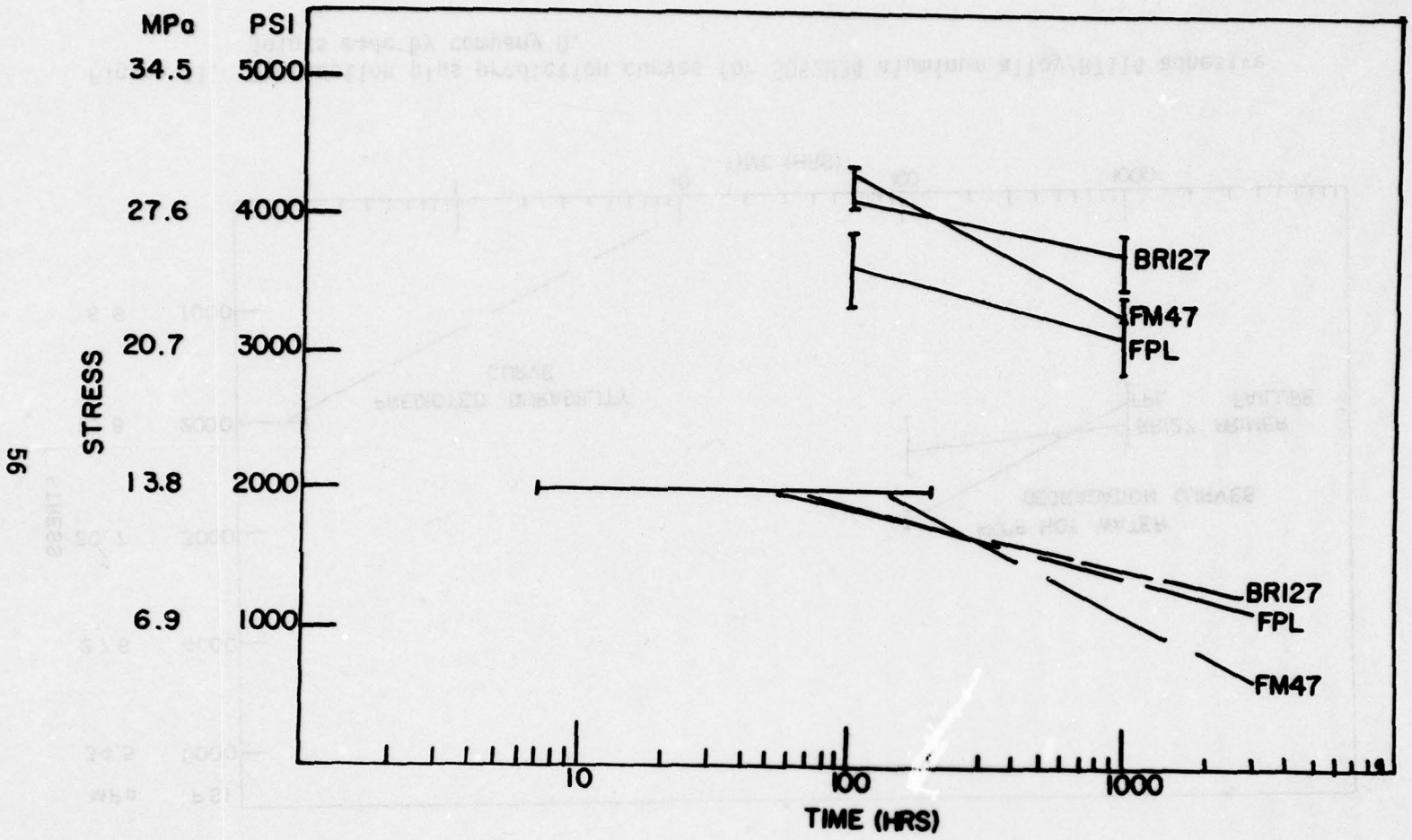


Figure 12. Degradation plus prediction curves for 5052H34 aluminum alloy/EA9601 adhesive joints made by company E.

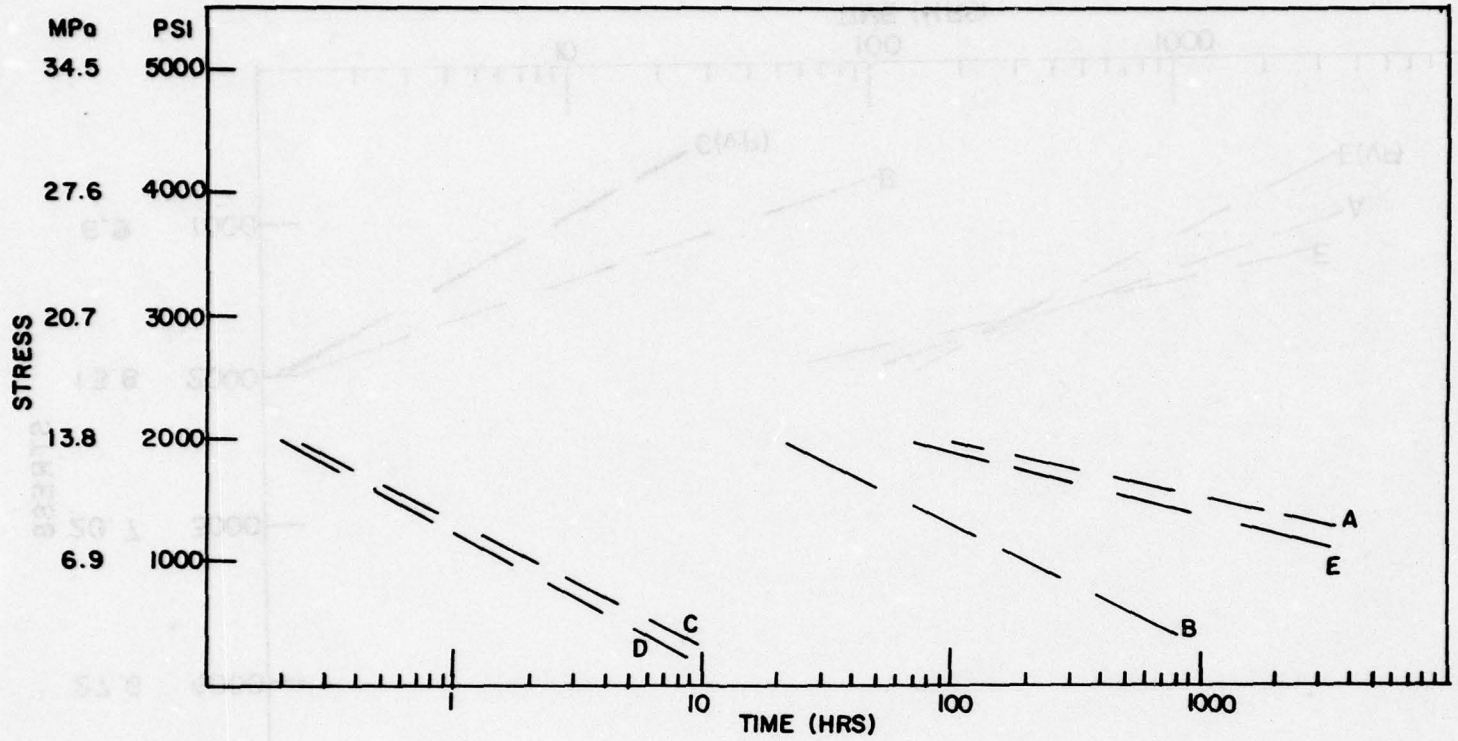


Figure 13. Comparison of predicted durability curves for FPL etched 5052H34 aluminum alloy joints.

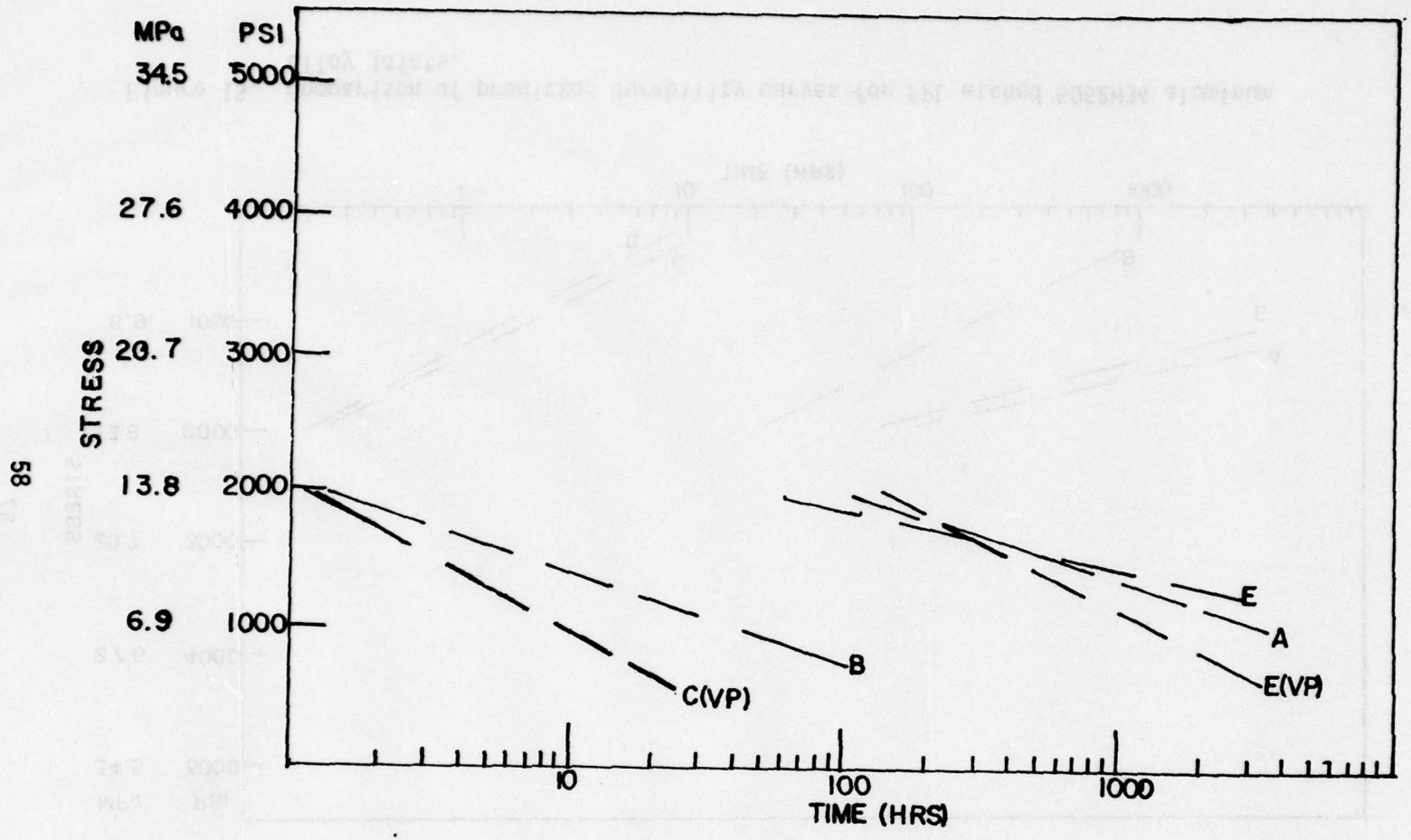


Figure 14. Comparison of predicted durability curves for FPL etched plus primed 5052H34 aluminum alloy joint.

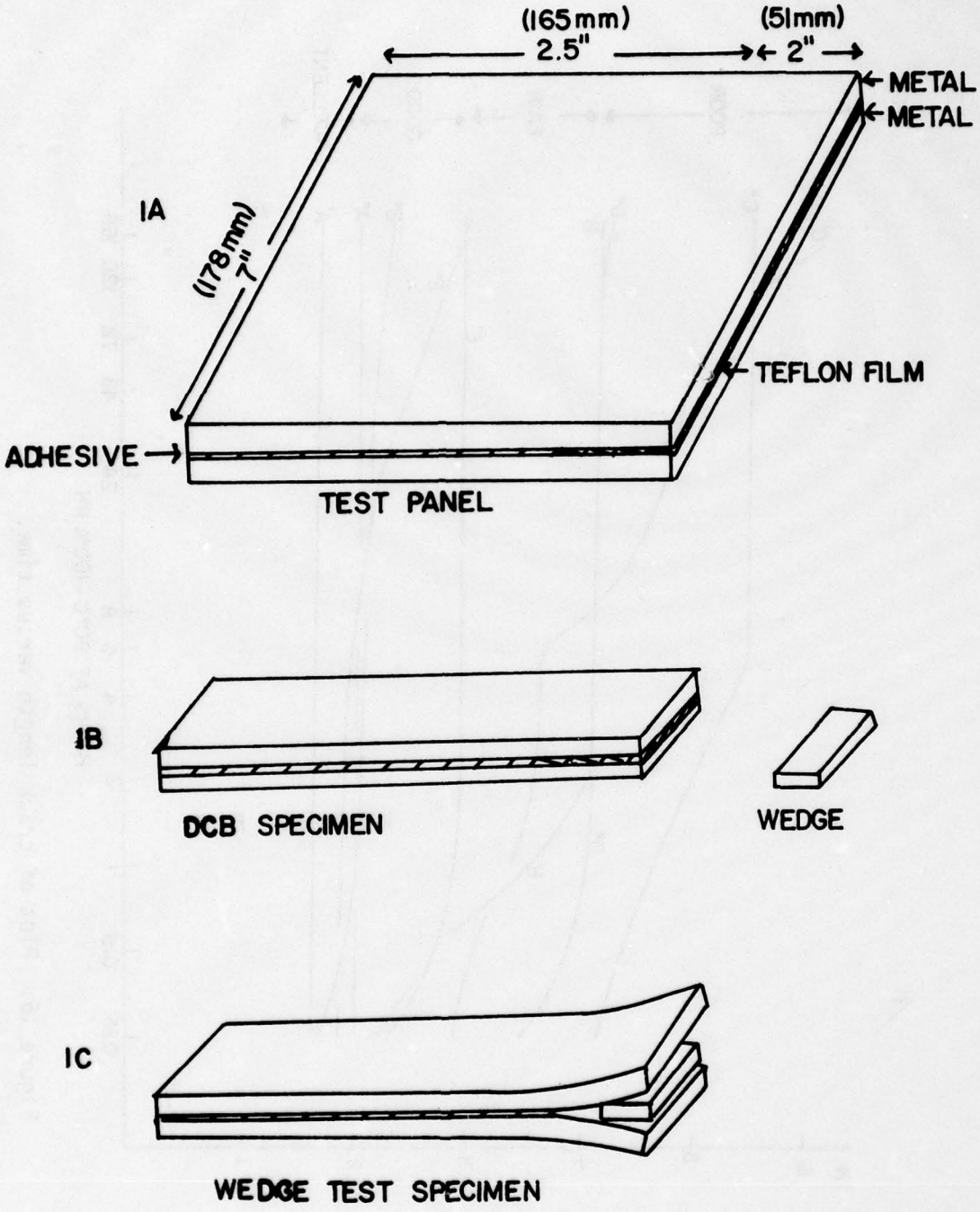


Figure 15. Sketch showing fabrication of wedge test.

Figure 16. Plot of crack length versus time.

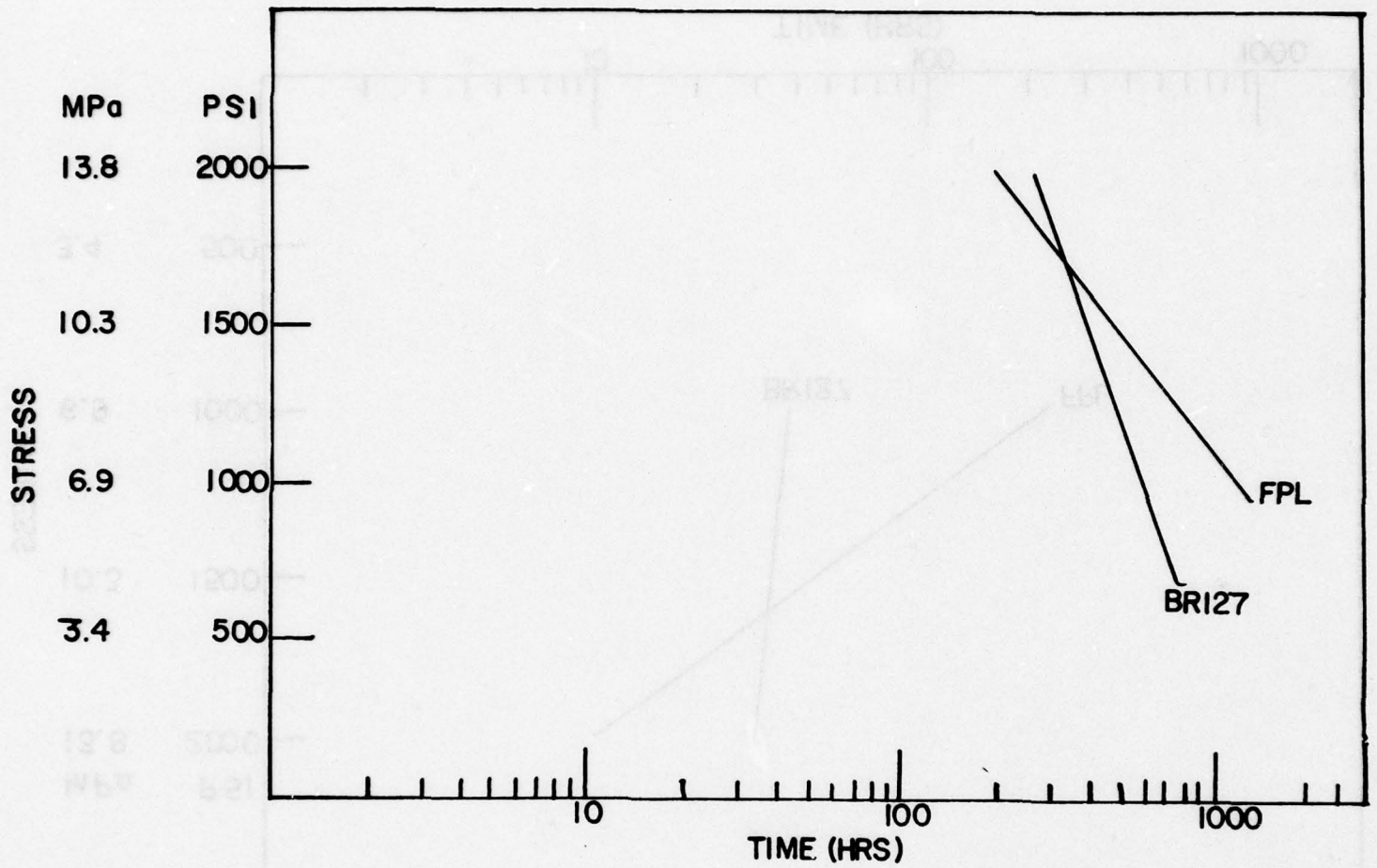


Figure 17. Durability curves - company A - 6061T-6 aluminum-7114 adhesive.

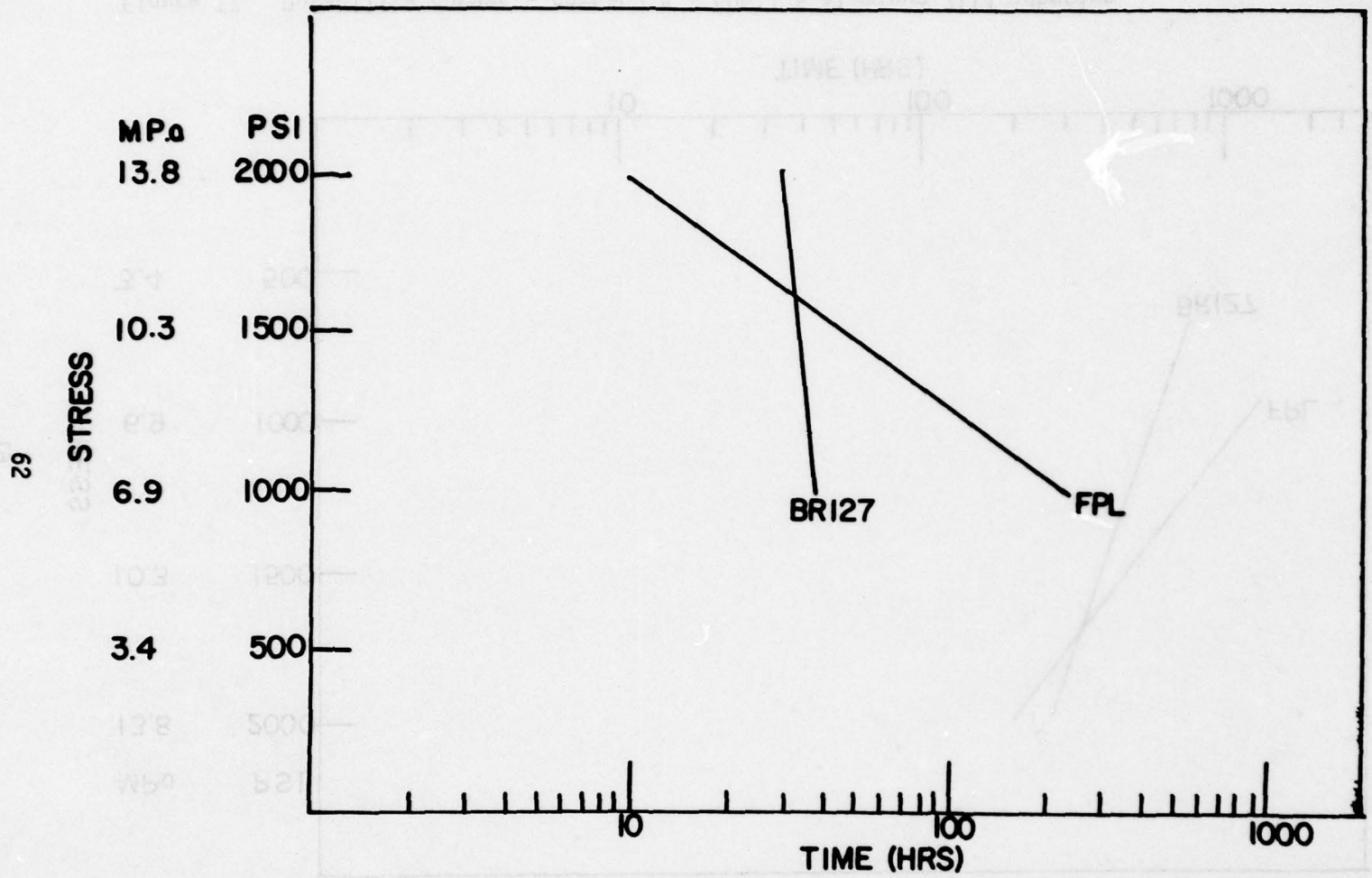


Figure 18. Durability curves - company B - 6061T-6 aluminum-7114 adhesive.

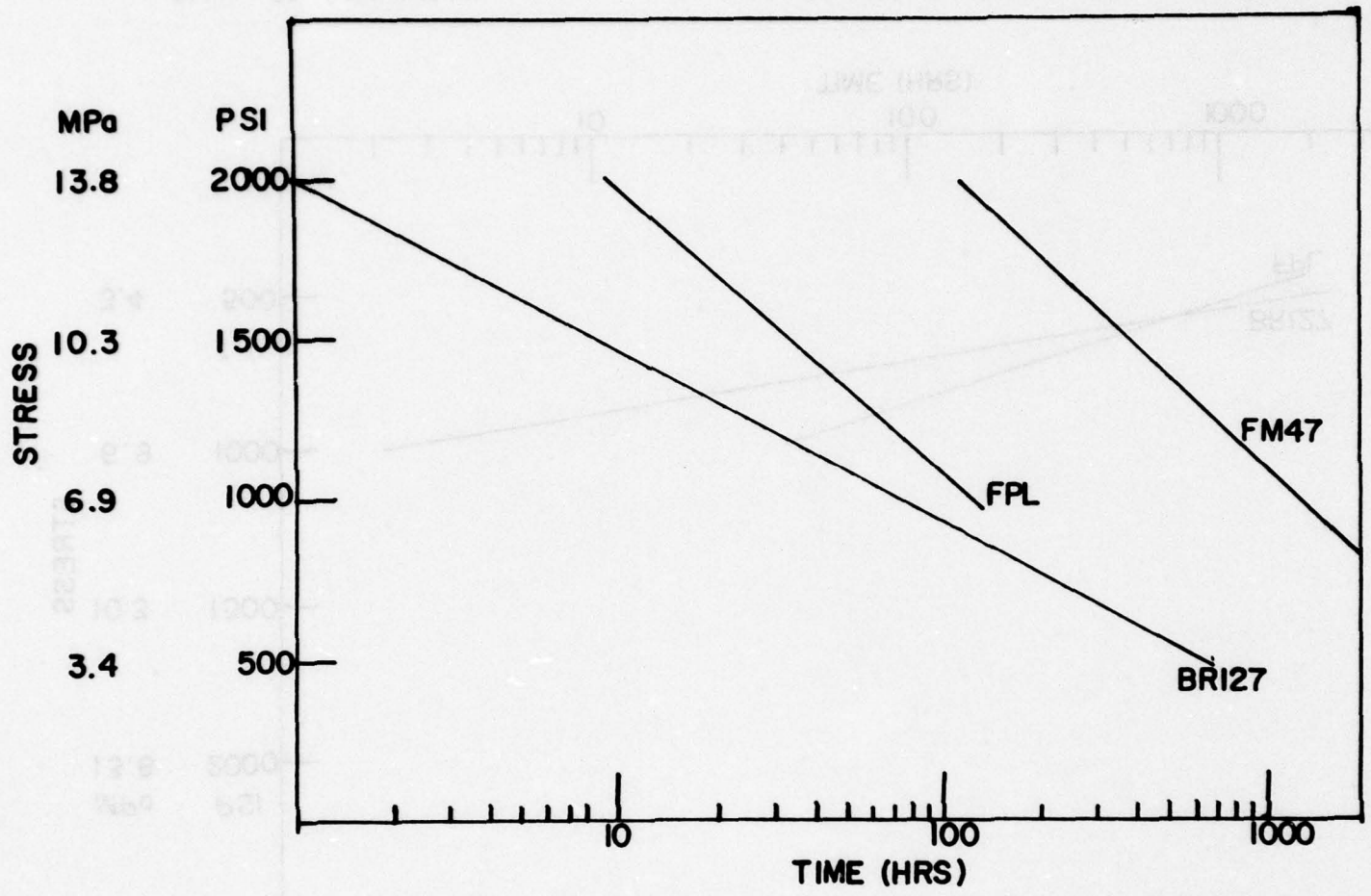


Figure 19. Durability curves - company C - 6061T-6 aluminum-7114 adhesive.

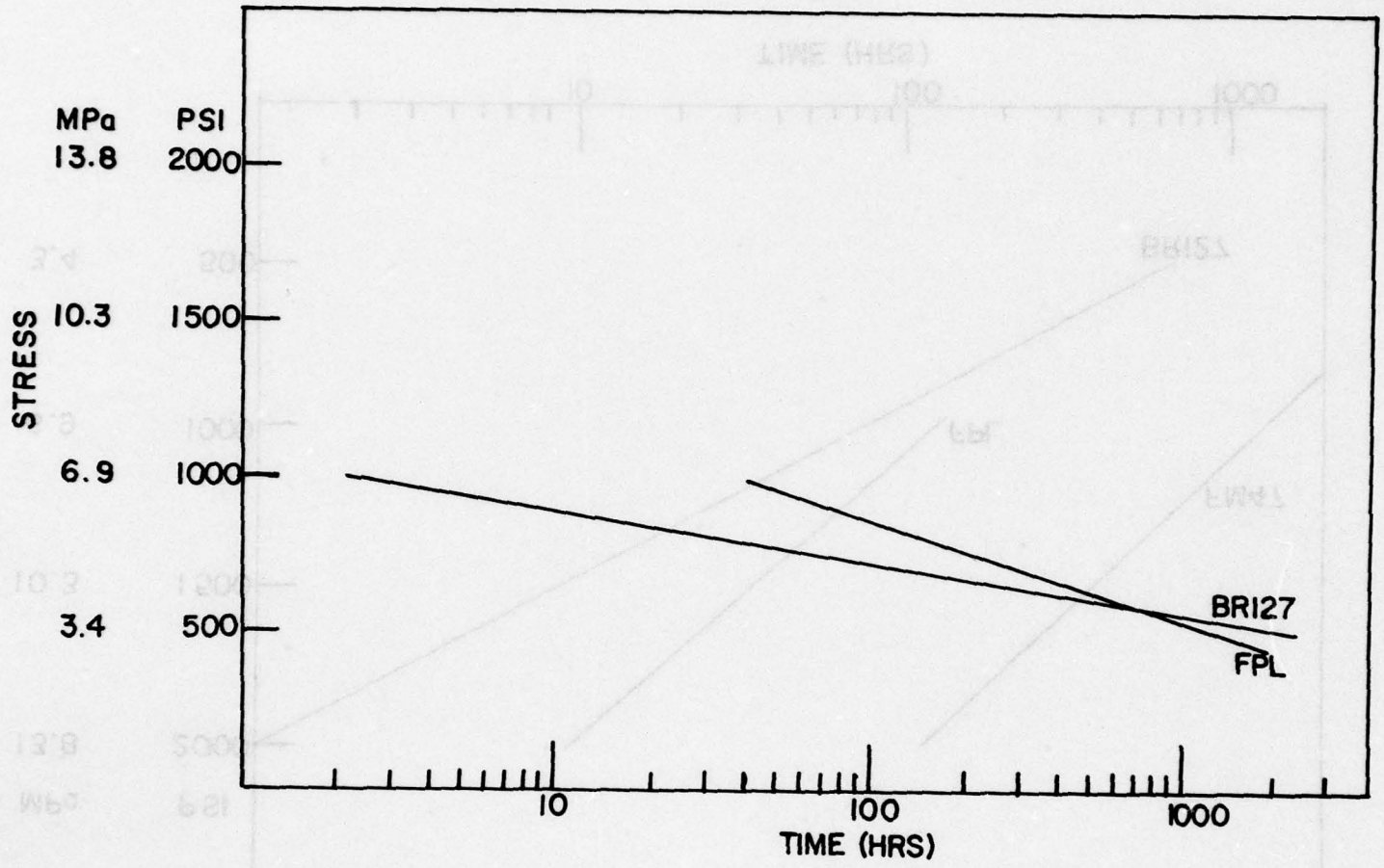


Figure 20. Durability curves - company D - 6061T-6 aluminum - 7114 adhesive.

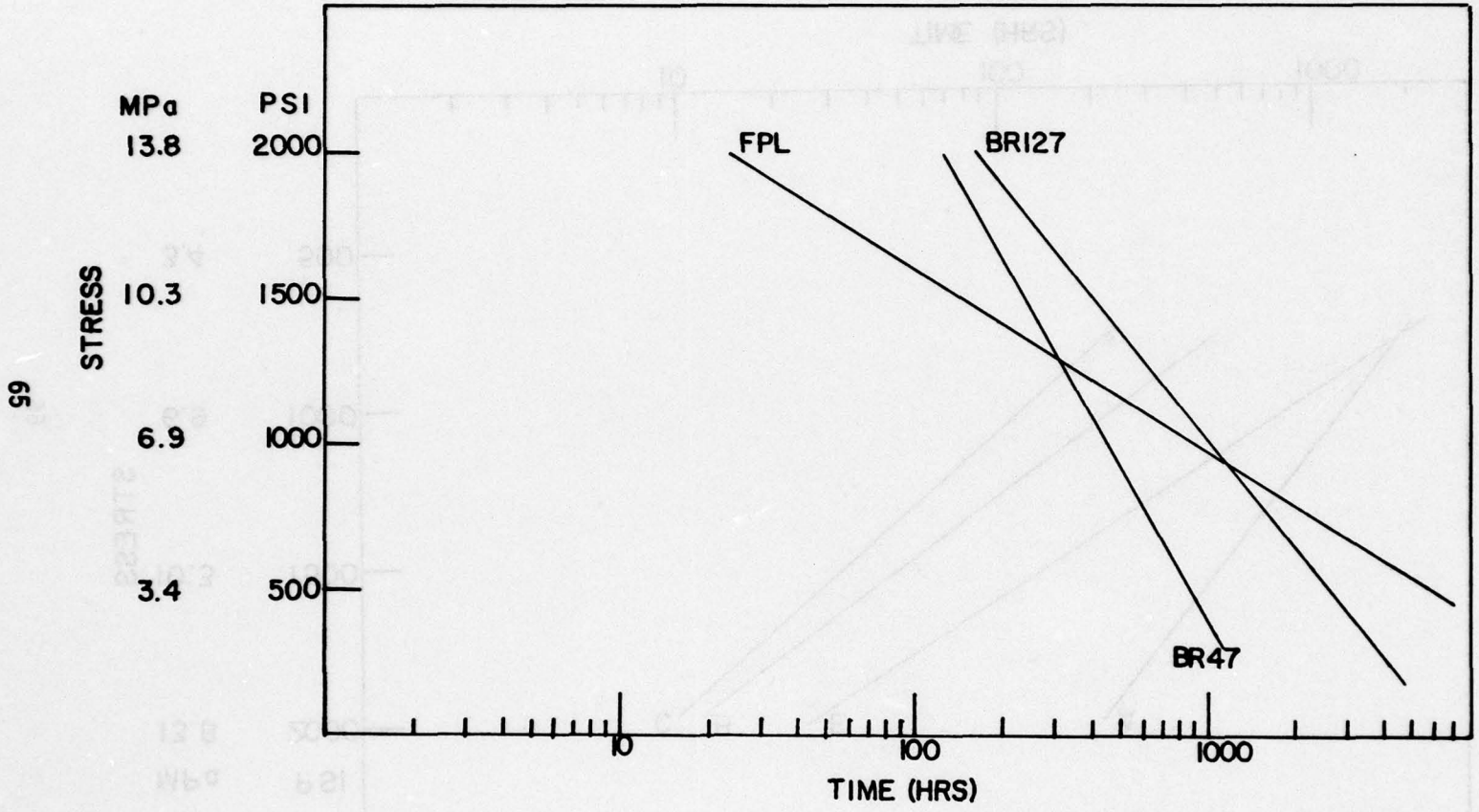


Figure 21. Durability curves - company E - 6061T-6 aluminum - 7114 adhesive.

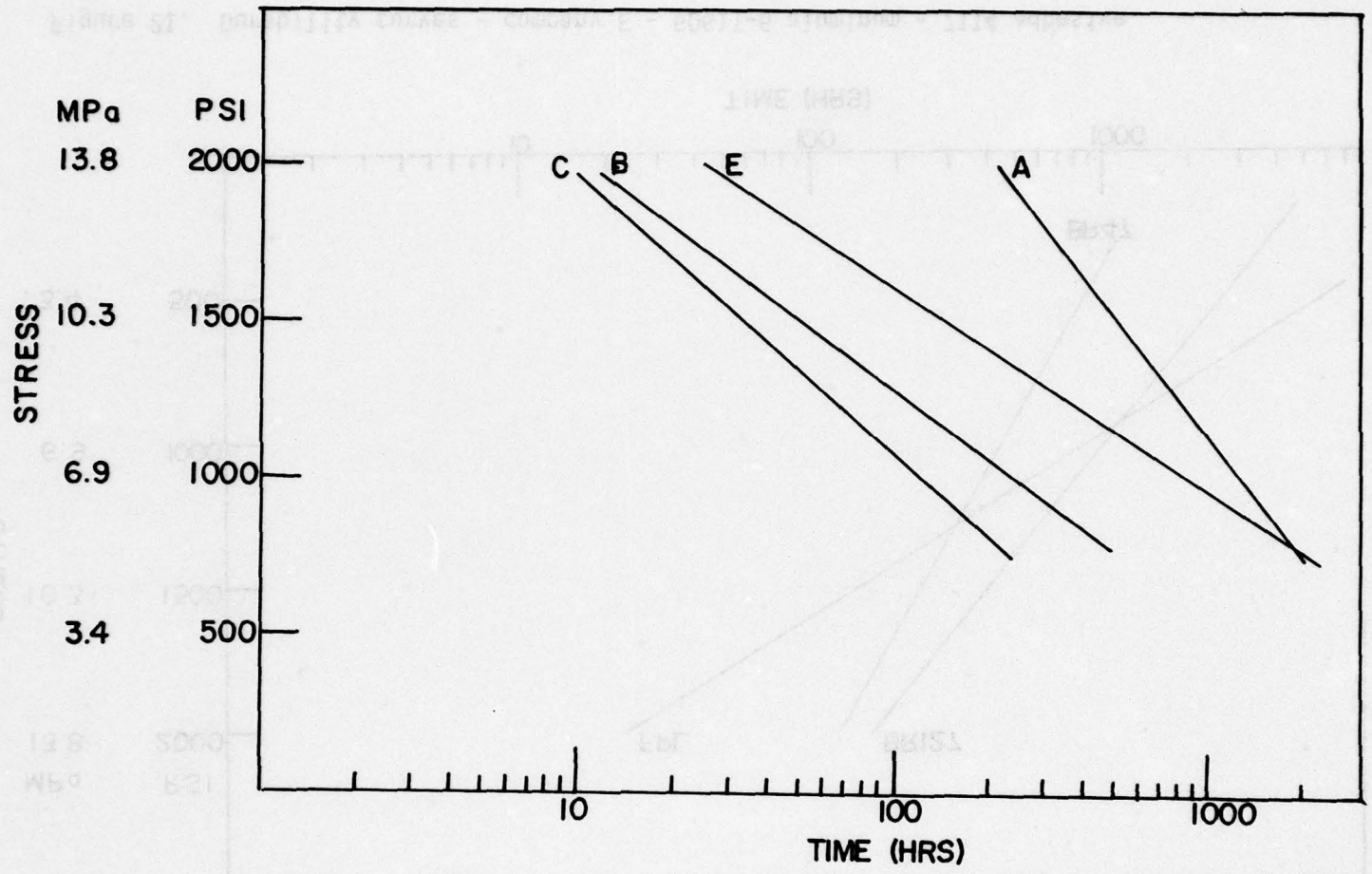


Figure 22. Comparison of durability curves - 6061T-6 aluminum - FPL etched, no primer from four companies.

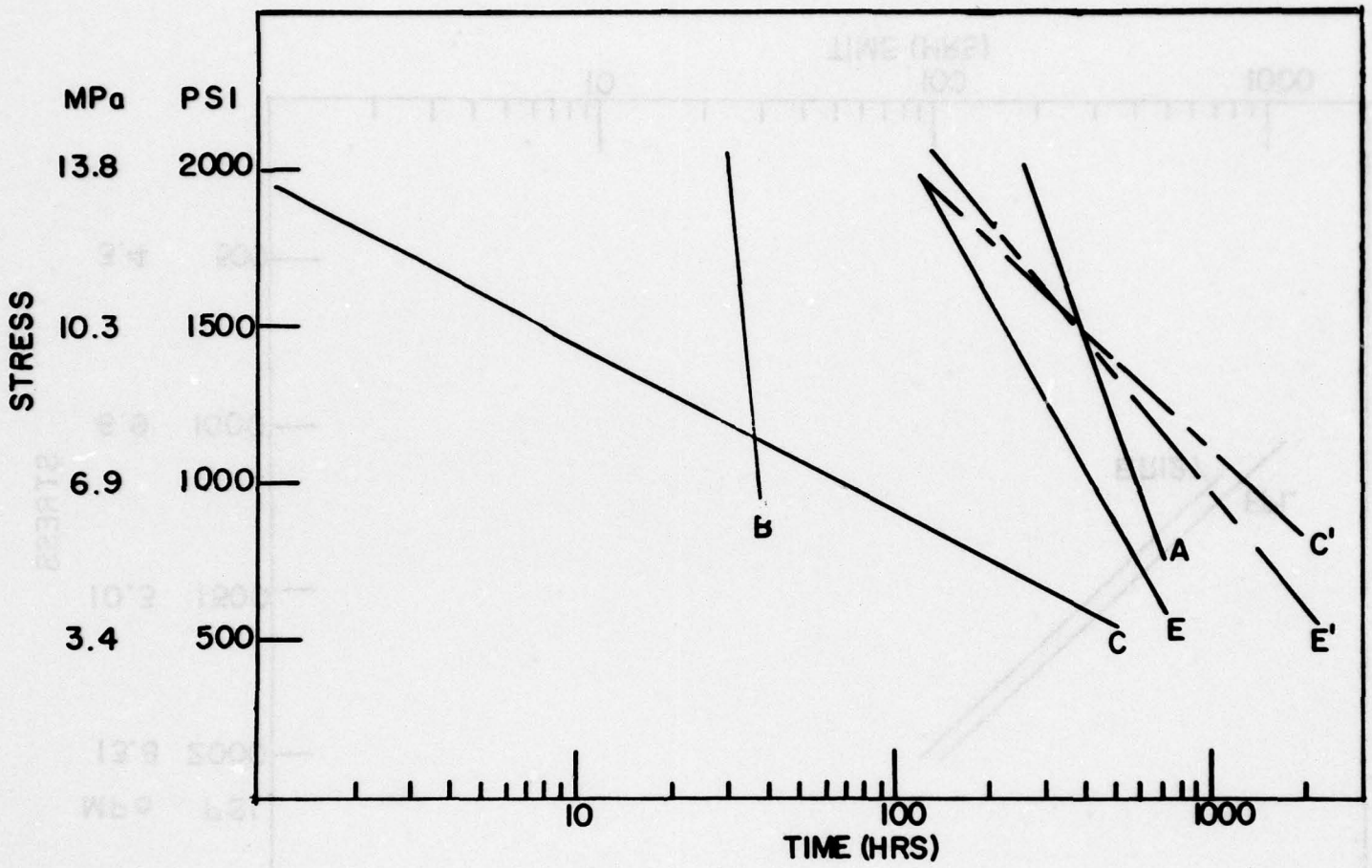


Figure 23. Comparison of durability curves - 6061T-6 aluminum - FPL etched, primed from five companies.

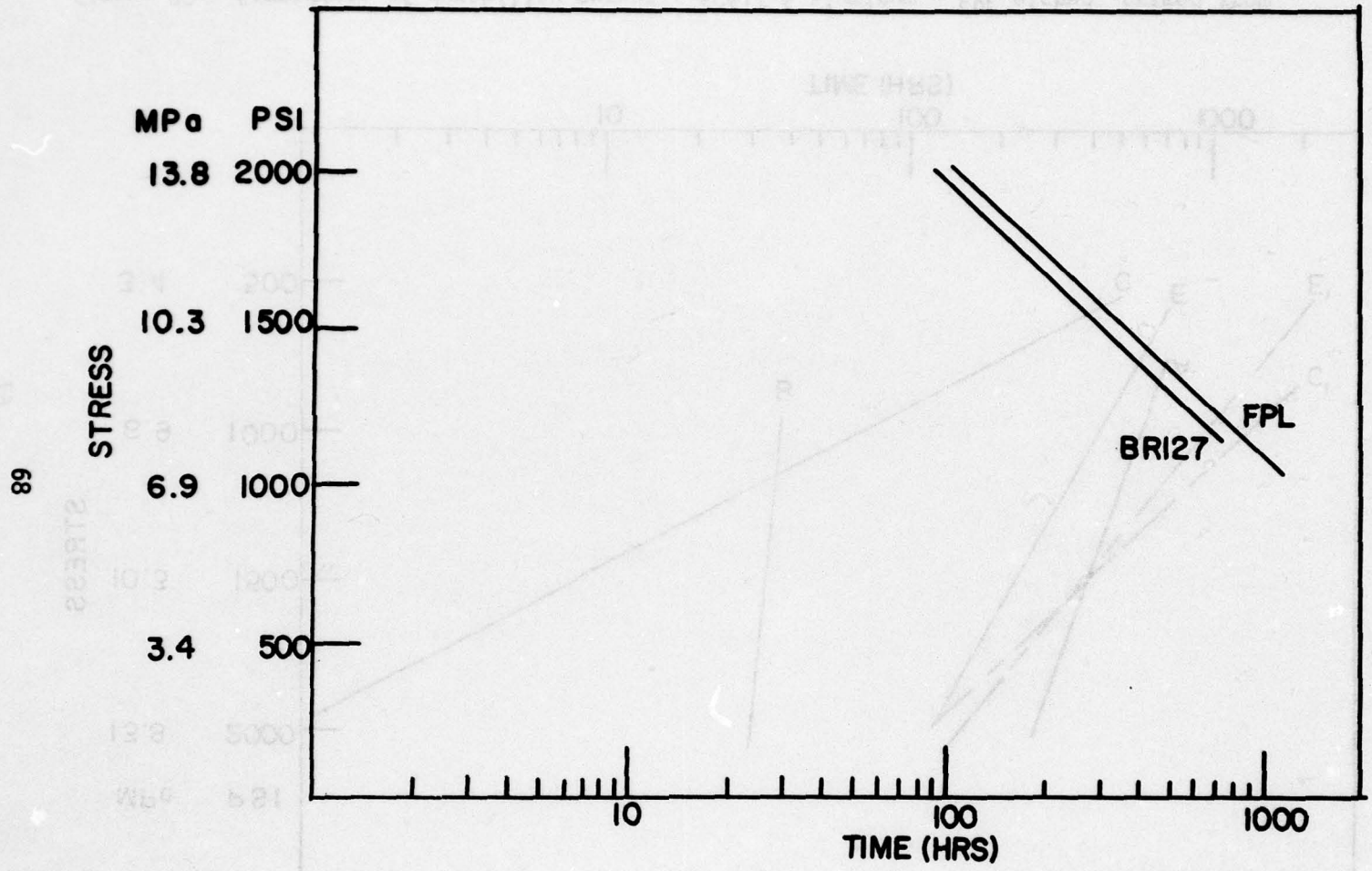


Figure 24. Durability curves - company A - 5052H34 aluminum - 7114 adhesive.

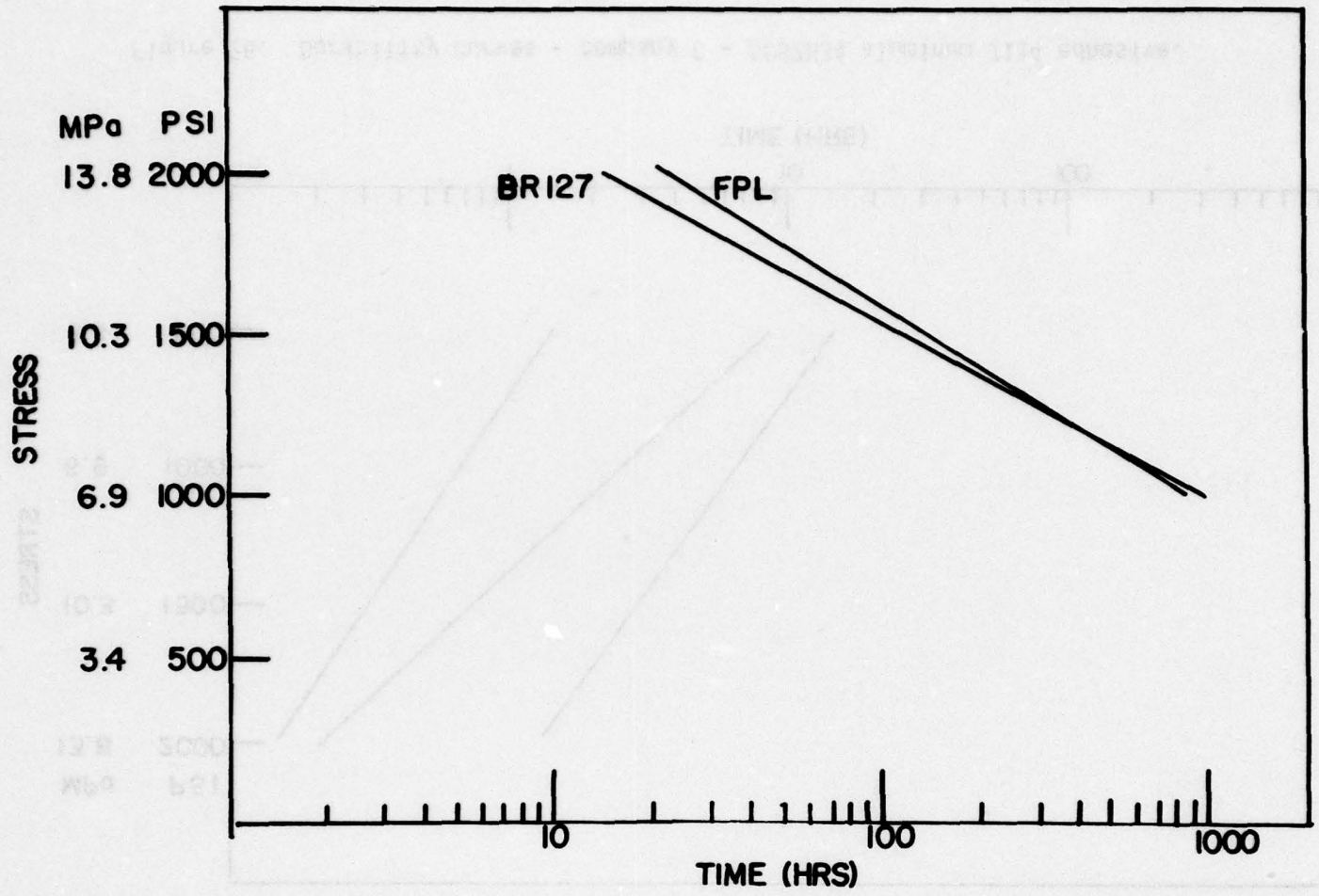


Figure 25. Durability curves - company B - 5052H34 aluminum - 7114 adhesive.

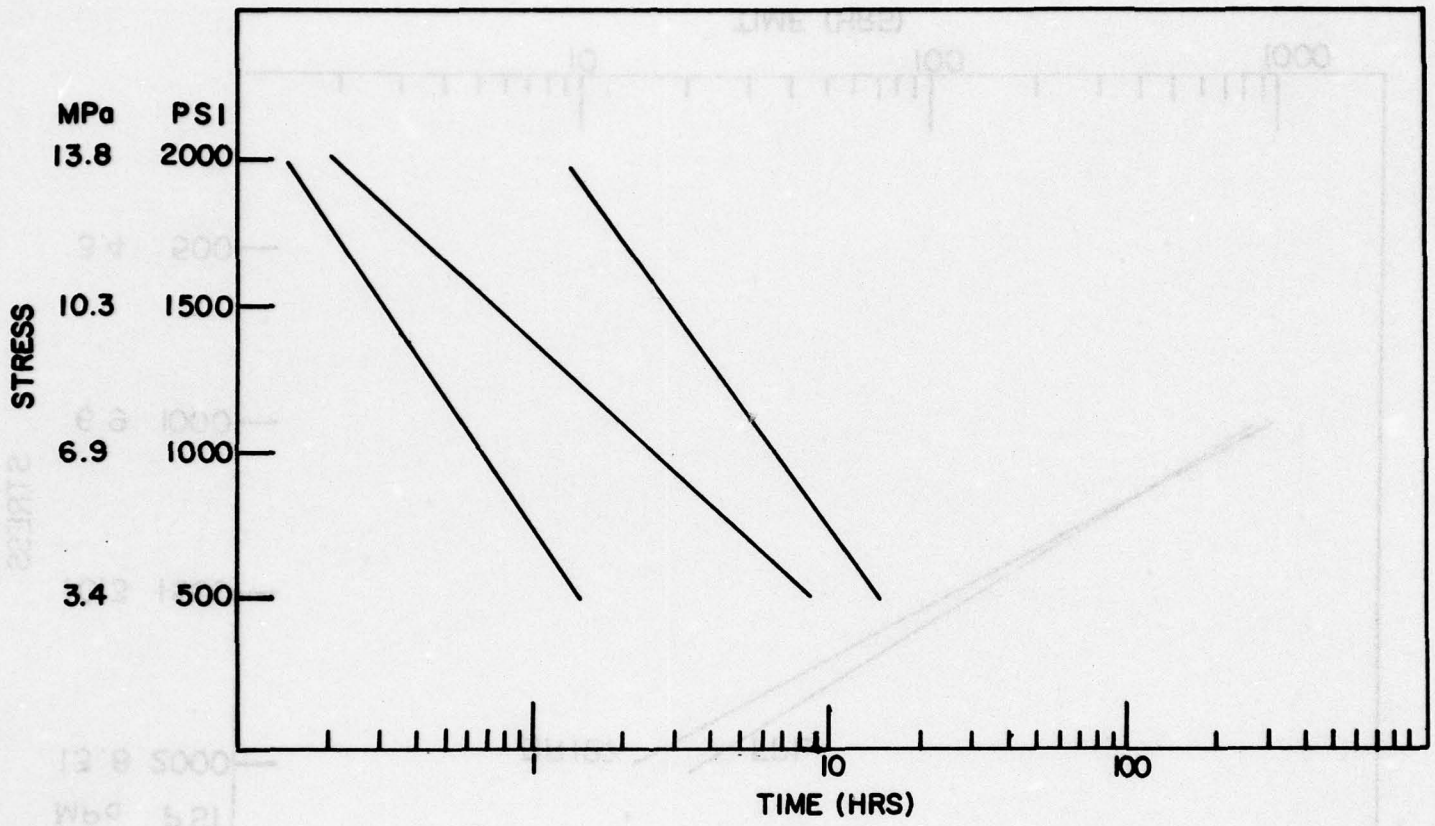


Figure 26. Durability curves - company C - 5052H34 aluminum 7114 adhesive.

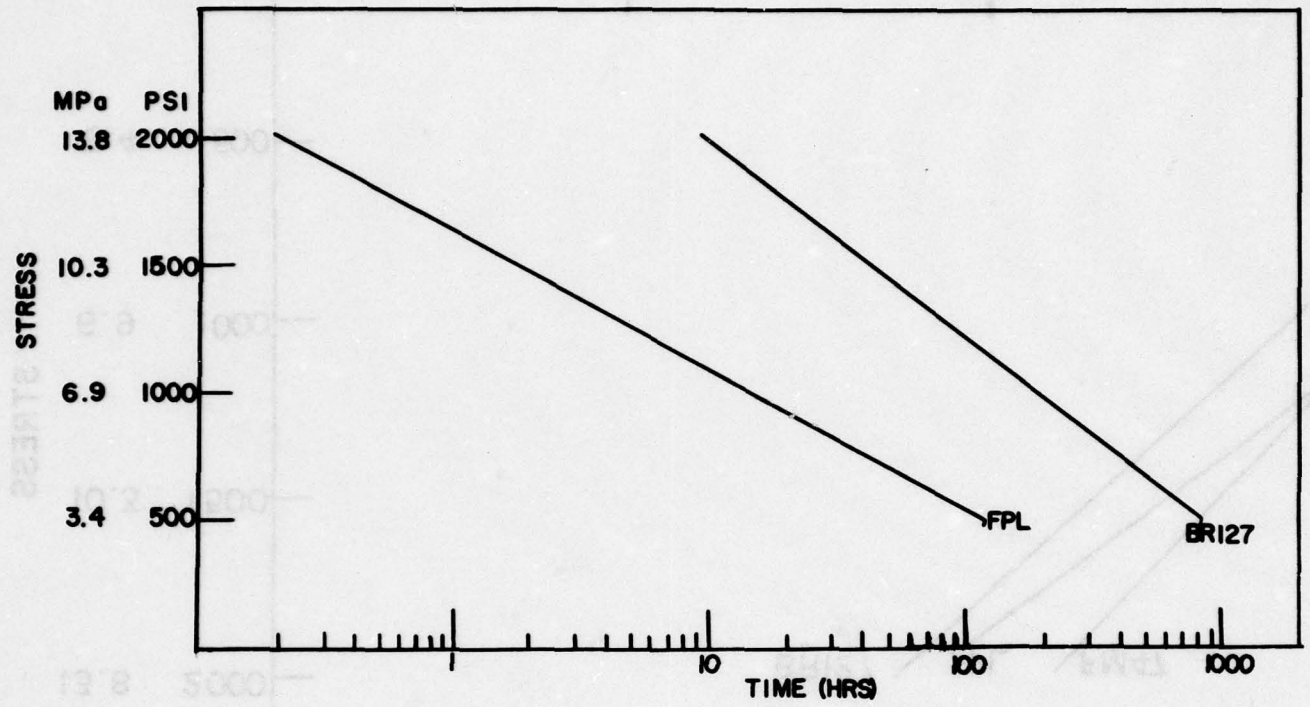


Figure 27. Durability curves - company D - 5052H34 aluminum - 7114 adhesive.

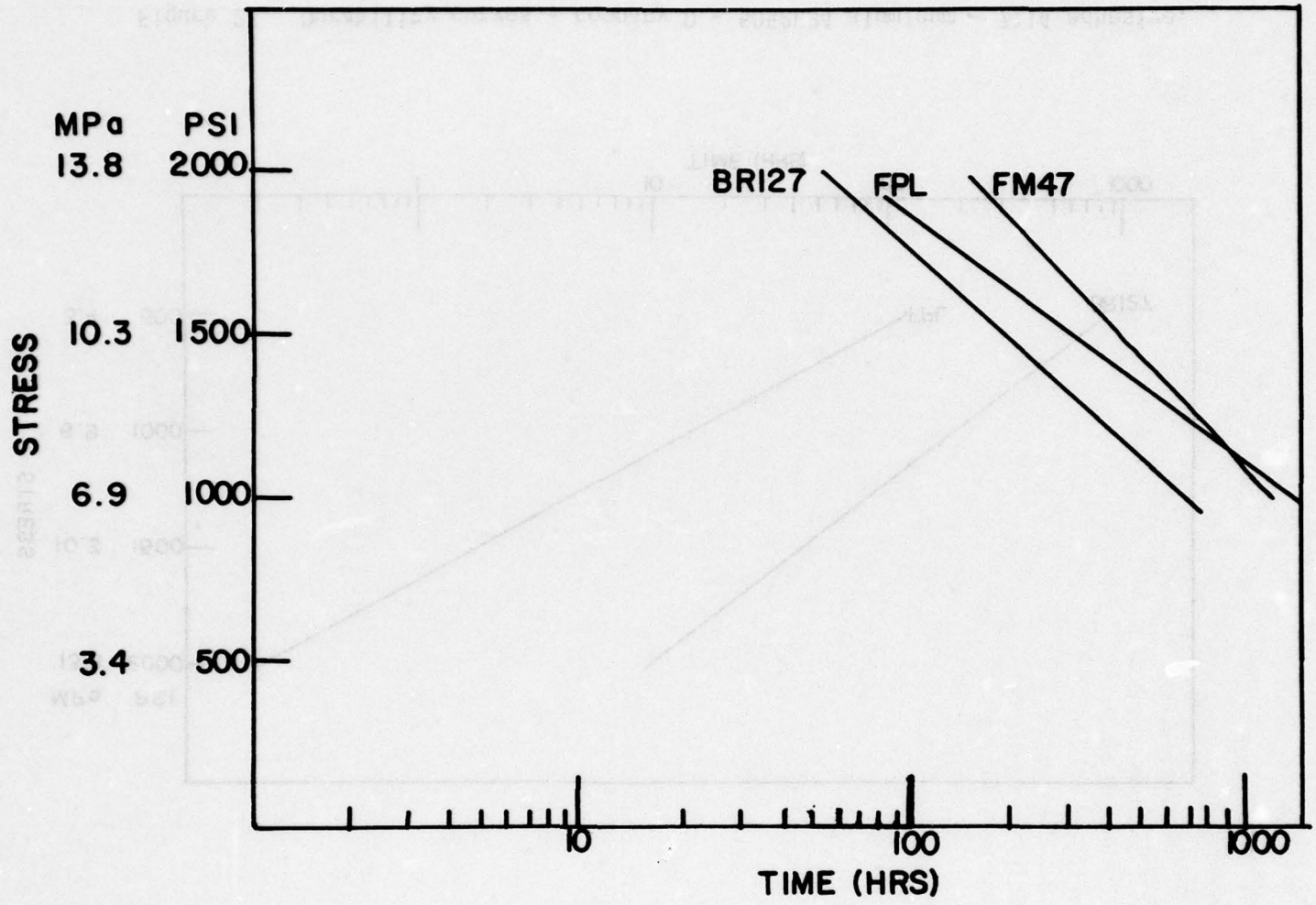


Figure 28. Durability curves - company E - 5052H34 aluminum - 9601 adhesive.

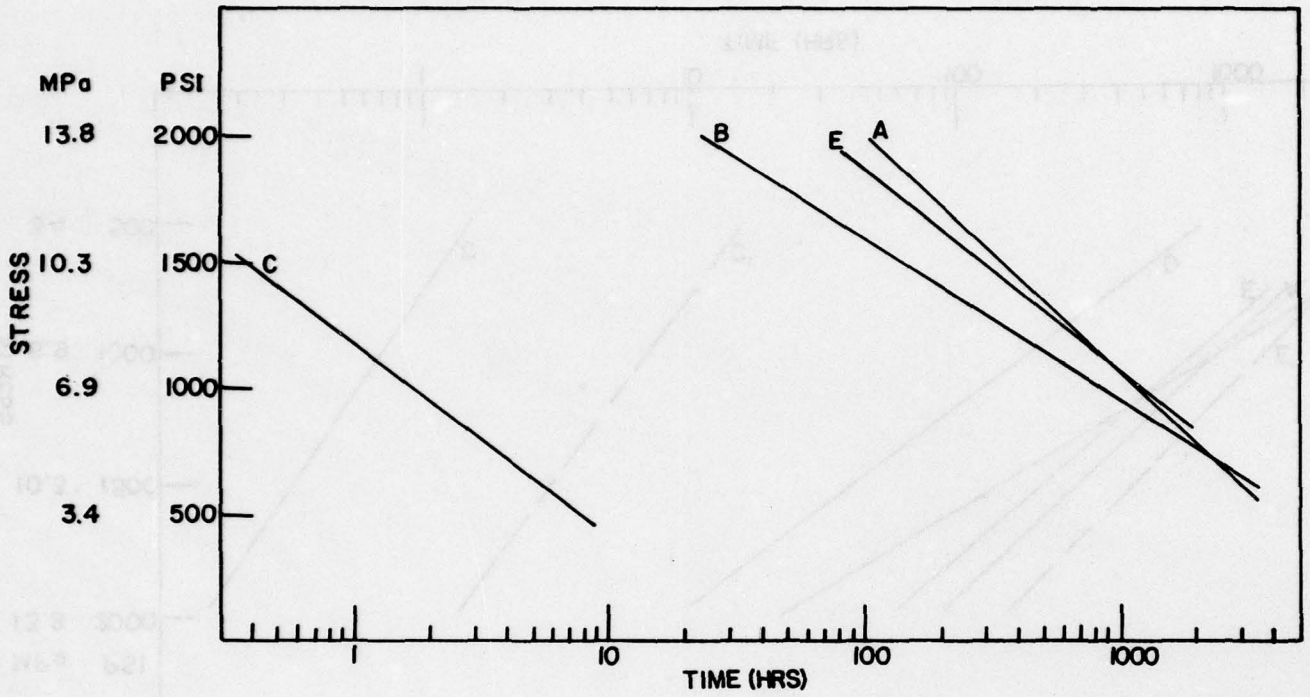


Figure 29. Comparison of durability curves - 5052H34 aluminum - FPL etched, no primer from four companies.

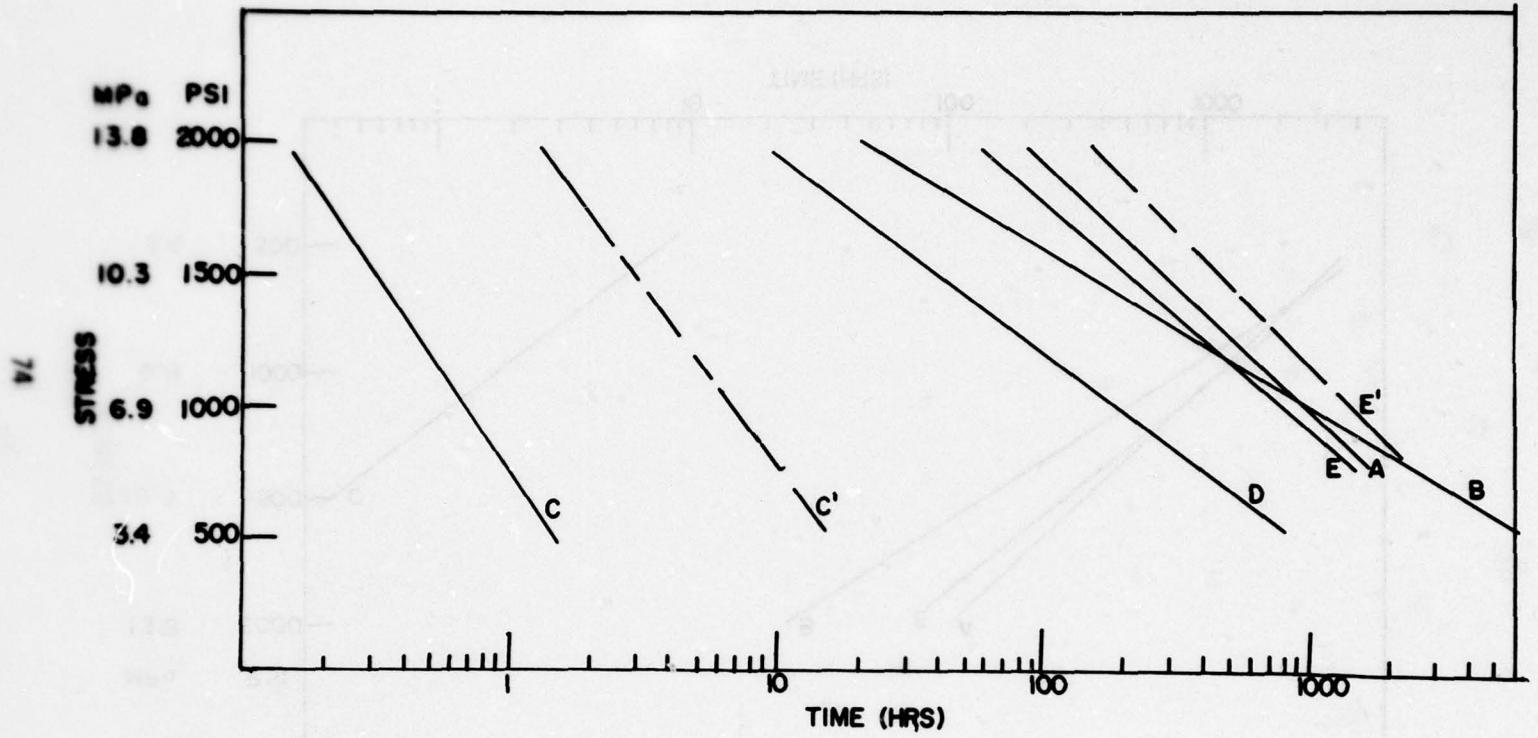


Figure 30. Comparison of durability curves - 5052H34 aluminum FPL etched, primed - from five companies.

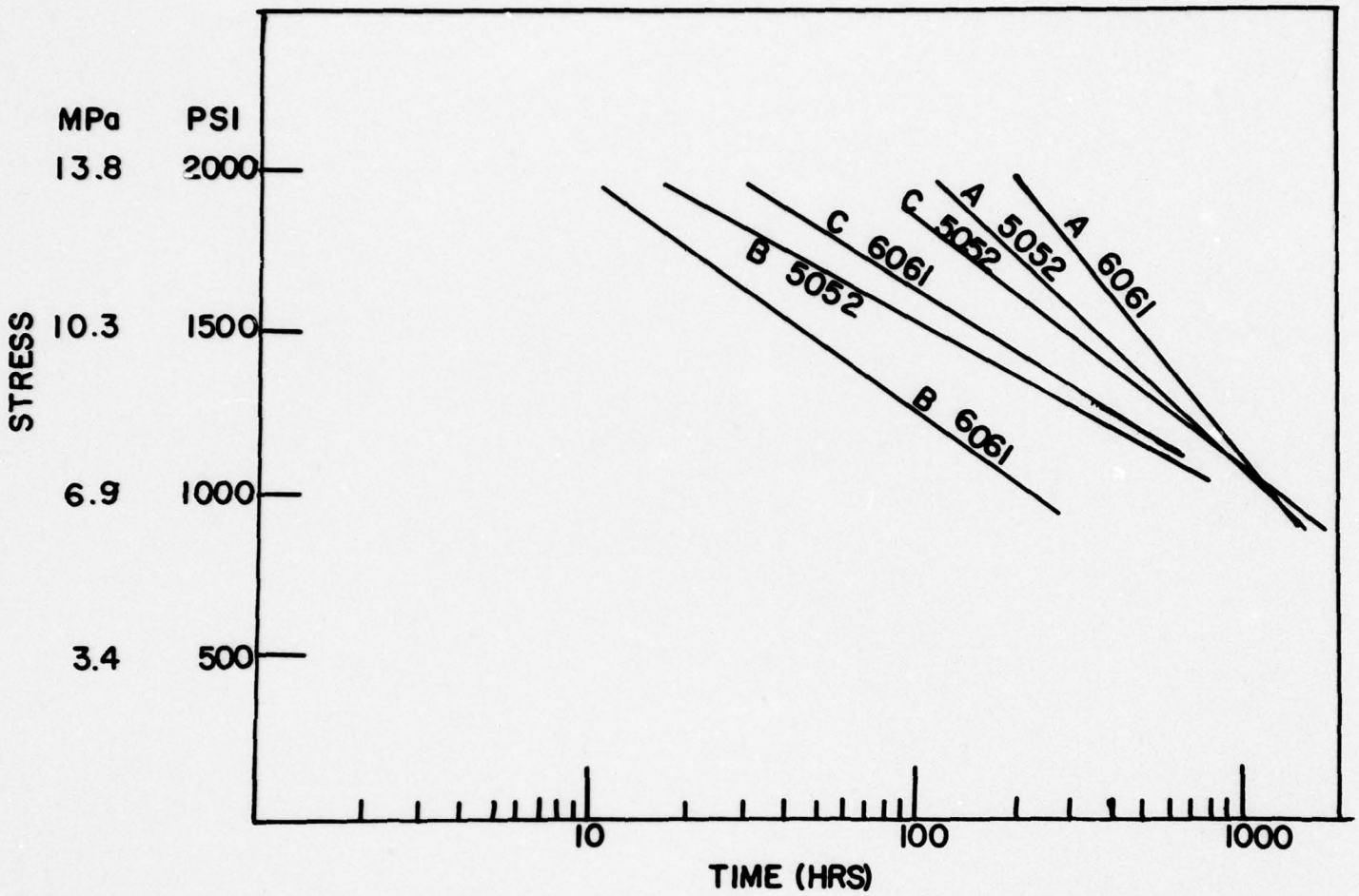


Figure 31. Comparison of durability curve - FPL etched, no primer, 5052H34 versus 6061T-6 alloy three companies.

DISTRIBUTION LIST

Commander
U.S. Army Armament Research and Development Command
ATTN: DRDAR-TSS (5)
DRDAR-LCA-OA, Mr. R. Wegman (20)
DRDAR-LCA-OK, Mr. A. Landrock (2)
Dover, NJ 07801

Commander
U.S. Army Troop Support & Aviation Materiel Readiness Command
ATTN: DRSTS MEN (2)
Mr. L.D. Brown (2)
P.O. Box 209
St. Louis, MO 63166

Commander
U.S. Army Natick Research & Development Command
ATTN: DRXNM-UST, Mr. Jack Siegel (2)
Natick, MA 07160

Commander
U.S. Army Electronics Command
ATTN: AMSEL-RD-ET-3, Mr. William Carl
Fort Monmouth, NJ 07703

Commander
Aeronautical Systems Division
ATTN: AFML/MXE, Mr. J. Rhodehamel
Wright Patterson Air Force Base, OH 45433

Commander
Hanscom Air Force Fase
ATTN: ESD/DE Stop 7, Mr. R. Karlson
HQ, ESD
Bedford, MA 01731

Commander
Air Force Civil Engineering Center
ATTN: HQ ADTC/CNS, CPT Monte H. Callen, Jr.
Tyndal AFB, FL 32401

Commander
Rome Air Development Center
ATTN: HQ AFSC, Mr. J. Guba (TUGS)
Griffin Air Force Base
Rome, NY 13440

National Bureau of Standards
ATTN: Dr. G. Frohnsdorff (2)
Rm B-348 Building Research
Washington, DC 20234

Defense Documentation Center
Cameron Station
Alexandria, VA 22314 (12)

Parsons of California
ATTN: Mr. Don Biddle
3427 S. Airport Way
P.O. Box 6139
Stockton, CA 95206

Goodyear Aerospace Corporation
ATTN: Mr. R.E. Austin
P.O. Box 85
Litchfield Park, AZ 85340

Nordam
ATTN: Mr. Pat McCoy
510 South Lansiky
Tulsa, OK 74120

Brunswick Corporation
ATTN: Mr. Roger Bowman
325 Brunswick Lane
Marion, VA 24354

Gichner Mobile Systems
ATTN: Mr. John Sepavich
Dallastown, PA

Hexcel Corporation
ATTN: Mr. J. Brentjes
Dublin, CA 94566

U.S. Army Armament Materiel Readiness Command
ATTN: DRSAR-LEP-L
Rock Island, IL 61299

Director
U.S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Tech Library)
White Sands Missile Range, NM 88002

Weapon System Concept Team/CSL
ATTN: DRDAR-ACW
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-CLJ-L
Aberdeen Proving Ground, MD 21005

Technical Library
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-LCB-TL
Benet Weapons Laboratory
Watervliet, NY 12189

U.S. Army Materiel Systems Analysis Activity
ATTN: DRXSY-MP
Aberdeen Proving Ground, MD 21005