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EUREKA 269 - FATIGUE TESTS ON SMALL SCALE BONDED
JOINTS
Overview of test results and statistical analysis.

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To:

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Author(s) : O.D. Dijkstra,
IJ.J. van Straalen and
F. Soetens

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SUMMARY

This report gives an overview of the fatigue test results on adhesive bonded joints in strips.

Specimens with a nominal thickness of 6 mm were used.

The testing parameters involved in the programme were:

- two alloys: 6061-T6 and 5754-WH
- two adhesives: 3M 9323 and 3M 7823
- two pretreatments: Degreasing and
Degreasing, etching, Chromate based Conversion
- two environments: air and water

These parameters result in a testing programme with 16 groups.

The specimen design was based on the static strength.

The results are presented and a statistical analysis with a multi regression technique was carried out on the test results.

A model with one slope for all the 16 groups proofed to be adequate.

One group (9) gives unrealistic high results compared to the rest of the results.

For the other groups a design line classification based on the relative fatigue load ($\Delta F/F_S$) at 2 million cycles is given. The classification ranges from 0.16 to 0.24 (see table 10).

In general water has little or a slightly negative influence on the life time and the chromate based conversion pretreatment has little or a positive influence on life time.

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1 INTRODUCTION

This report gives an overview of the fatigue test results on adhesive bonded joints in strips. The fatigue tests were carried out by 4 laboratories and this report provides the test results and a statistical analysis.

2 TEST PROGRAMME

The specimens consist of axially loaded overlap joints with cover plates on both sides in 6 mm thick strips (see figure 1).

In the fatigue experiments on the small scale adhesive joints the following testing parameters are involved:

- | | | |
|---|--------------------|--|
| A | two alloys: | 6061-T6 with $\sigma_{0.2}=240$ N/mm ² and $\sigma_u=260$ N/mm ²
5754-WH with $\sigma_{0.2}=140$ N/mm ² and $\sigma_u=220$ N/mm ²
(H 32) |
| B | two adhesives: | 3M 9323 with $\tau_u = 28$ N/mm ² and $\bar{\tau} = 21$ N/mm ²
3M 7823 with $\tau_u = 40$ N/mm ² and $\bar{\tau} = 30$ N/mm ² |
| C | two pretreatments: | D - Degreasing
CC - degreasing, etching, Chromate based
Conversion |
| D | two environments: | air
water |

This makes $2^4 = 16$ possible combinations of parameters.

The combination of alloy and adhesive determines the joint configuration (see section 3). So, in reality we have 4 types of test specimens. This does not effect the experimental design.

The original test programme consists of 12 tests for all combinations with the CC-pretreatment and 4 tests for all combinations with the D-pretreatment. So, the number of tests in the original programme is $(8*12)+(8*4)=128$ (The final programme was slightly different from the original one).

The programme was carried out by 4 (5) laboratories:

- 1 Pechiney
- 2 Porto
- 3 Alcan
- 4(5) BNF (later on it was decided that some specimen will be tested by TWI)

The experimental design has been made with the following conditions:

- a The experiments will be equally distributed among the 4 laboratories. So, each laboratory will test 32 specimens.
- b All the tests for one combination of parameters will be carried out by the same laboratory. This simplifies the testing and the reporting of the results.
- c The laboratories are considered as blocks in the experimental design. The design is made in such a way that a possible laboratory effect is confounded with the two factor interaction A*D and the three factor interactions A*B*C and B*C*D.

These conditions lead to the test programme given in table 1, with 16 different groups.

The distribution of the tests among the laboratories is also given in table 1.

3 SPECIMEN DESIGN

The specimen were designed in such a way that the ultimate strength of the joint is at least as strong as the yield strength of the connected members. Doing so the design of the connection is in agreement with the design philosophy for static strength. However, this leads to a different length of the cover plates and different values for the shear stress in the adhesive.

The fatigue load is chosen as a ratio to the yield strength of the connected members.

Yield strength connected member is:

$$F_{\text{member, y}} = T \cdot W \cdot \sigma_{0.2} \quad (1)$$

Ultimate strength joint is:

$$F_{\text{joint}} = L_c \cdot W \cdot \bar{\tau} \quad (2)$$

So, the length of the cover plates is determined as follows:

$$L_c = T \cdot \frac{\sigma_{0.2}}{\bar{\tau}} \quad (3)$$

The dimensions and the stresses at the yield point of the connected member are given in table 2.

4 TEST RESULTS

Tests were carried out at three different fatigue load levels (ratio fatigue load to yield strength of the connected member), namely 0.30, 0.42 and 0.60. Most of the tests were carried out with a load level of 0.42. Only for the joints with the CC pretreatment tests were carried out at all the three load levels.

The test results are given in table 3. The tests carried out by Alcan were not carried out at the load levels as given in table 3, therefore these tests results are given in table 4.

5 STATISTICAL ANALYSIS

5.1 Method

5.1.1 General

The results will be analyzed with a multi regression analysis using the STAT-GRAPHICS 3.0 software.

A multiple linear regression analysis of the results of the following type is used:

$$Y = m_0 + m_1 * X_1 + m_2 * X_2 + \dots + m_n * X_n \quad (4)$$

In this analysis a linear relation between the dependent variable Y and a number of independent variables X is assumed.

In fatigue analyses the results are often presented in a double log graph, with the number of cycles (N) on the horizontal axis and the stress range (S) on the vertical axis and the influence of special effects are often presented as factors on lifetime. So, it is more convenient to use the logarithm of the parameters in the regression analysis.

In fatigue analyses the number of cycles (N) is generally considered as the dependent variable. So equation (4) was modified as follows:

$$\log(N) = m_0 + m_S * \log(S) + m_{E1} * \log(E_1) + \dots + m_{En} * \log(E_n) \quad (5)$$

where: m_0 = constant determining the position of the S-N curve
 S = stress or load range
 m_S = exponent determining the slope of the S-N line
 E_1 = other influencing parameters
 m_{E1} = exponent for the influence of parameter E_1
 etc,

The independent variables can be numerical parameters or qualitative parameters. For numerical parameters the numerical value of the parameter is used in these equations. The stress or load range is a numerical parameter.

The treatment of qualitative parameters is given in section 5.1.2.

5.1.2 Qualitative parameters

The qualitative independent variables are the alloy, the adhesive, the pretreatment, the environment and the laboratory. Alloy and adhesive determine the specimen type (see section 2). For qualitative parameters a so called 'dummy variable' can be used to investigate the influence of the qualitative parameter.

For a qualitative parameter with two different situations the dummy variable is set to two different values for two different situations. For more than two different situations interaction has to be taken into account (see section 5.1.3 and 5.2.1.1).

As an example the variable air/water can be set to the following values:

"10"	for air
"20"	for water

5.1.3 Interaction effects

It is possible that the effect of a certain parameter is influenced by the value of another parameter. This effect is called interaction. The presence of possible interaction effects can be analyzed by considering the product of both parameters as a new parameter in the analysis. Interaction of two parameters is called two-factor interaction. Interaction of more than two parameters is also possible.

The following equation gives the format for an analysis with interaction between parameter S and E_1 .

$$\log(N) = m_0 + m_S \cdot \log(S) + m_{E_1} \cdot \log(E_1) + m_{SE_1} \cdot \log(S) \cdot \log(E_1) \quad (6)$$

5.2 Multi regression analyses

5.2.1 Format of the analyses and results

5.2.1.1 Parameters

a) Numerical parameters

The only numerical parameter is the load range (S). As mentioned before the relative load range ($\Delta F/F_S$) is used as the governing parameter. This parameter has to be taken into account in any analysis. Interaction of this parameter with other (dummy) parameters means regression lines with different slopes for different groups of specimens. Without interaction the slope of the S-N curve is the same for all groups of specimens.

b) Qualitative or dummy parameters

The following dummy parameters were used:

A	alloy	10	for 6061-T6
		20	for 5754-WH
B	adhesive	10	for 9323
		20	for 7823
C	pretreatment	10	for D
		20	for CC
D	environment	10	for air
		20	for water
L1	laboratory	10	for Pechiney(1) and Porto(2)
		20	for Alcan(3) and BNF(4)
L2	laboratory	10	for Pechiney(1) and Alcan(3)
		20	for Porto(2) and BNF(4)

As stated in section 2 we have tested four types of specimens, determined by the alloy and the adhesive. These four specimens can be distinguished by the dummy parameters A and B and the interaction A*B. As we want to distinguish the four specimen types the parameters mentioned need to be present in any analysis. The specimen types can be distinguished, as follows:

A & B	10 & 10	for 6061-T6 / 9323
A & B	10 & 20	for 6061-T6 / 7823
A & B	20 & 10	for 5754-WH / 9323
A & B	20 & 20	for 5754-WH / 7823

We also want to distinguish the effect of pretreatment and environment in any analysis. So, C and D need to be present in any analysis.

The four laboratories can be distinguished by the dummy parameters L1 and L2 and the interaction L1*L2. The laboratory can be distinguished as follows:

L1 & L2	10 & 10	for Pechiney (1)
L1 & L2	10 & 20	for Porto (2)
L1 & L2	20 & 10	for Alcan (3)
L1 & L2	20 & 20	for BNF (4)

5.2.1.2 Format

The format to be used for the analysis has to be a compromise between simplicity (less accurate) and completeness (complicated). A large number of analyses have been carried out. Five of them will be presented here. The five analyses can be characterized as follows:

- I An analysis with alloy (A), adhesive (B), interaction (A*B), pretreatment (C), environment (D) and load range (S) are taken into account (the most simple case).
- II An analysis with A, B, A*B, C, D, S and the laboratory effects (L1, L2 and L1*L2) are taken into account.
- III All parameters and possible interactions are taken into account, except the laboratory effects and interactions with the load range.
- IV All parameters and possible interactions are taken into account, except the laboratory effects (some interactions are not possible due to confounding with earlier parameters or interactions).
- V An analysis in which a possible laboratory effect can be determined and all parameters and possible interactions are taken into account (some interactions are not possible due to confounding with laboratory effects or others).

The equations for the regression analyses are as follows:

Analysis I

$$\log(N) = m_0 + m_a \cdot \log(A) + m_b \cdot \log(B) + m_{ab} \cdot \log(A) \cdot \log(B) + m_c \cdot \log(C) + m_d \cdot \log(D) + m_s \cdot \log(S) \quad (7)$$

Analysis II

$$\log(N) = m_0 + m_a \cdot \log(A) + m_b \cdot \log(B) + m_{ab} \cdot \log(A) \cdot \log(B) + m_c \cdot \log(C) + m_d \cdot \log(D) + m_s \cdot \log(S) + m_{l1} \cdot \log(L1) + m_{l2} \cdot \log(L2) + m_{l1l2} \cdot \log(L1) \cdot \log(L2) \quad (8)$$

Analysis III

$$\begin{aligned} \log(N) = & m_0 + m_a \cdot \log(A) + m_b \cdot \log(B) + m_{ab} \cdot \log(A) \cdot \log(B) \\ & + m_c \cdot \log(C) + m_d \cdot \log(D) + m_s \cdot \log(S) \\ & + m_{ac} \cdot \log(A) \cdot \log(C) + m_{ad} \cdot \log(A) \cdot \log(D) + m_{bc} \cdot \log(B) \cdot \log(C) \\ & + m_{bd} \cdot \log(B) \cdot \log(D) + m_{cd} \cdot \log(C) \cdot \log(D) \\ & + m_{abc} \cdot \log(A) \cdot \log(B) \cdot \log(C) + m_{abd} \cdot \log(A) \cdot \log(B) \cdot \log(D) \\ & + m_{acd} \cdot \log(A) \cdot \log(C) \cdot \log(D) + m_{bcd} \cdot \log(B) \cdot \log(C) \cdot \log(D) \\ & + m_{abcd} \cdot \log(A) \cdot \log(B) \cdot \log(C) \cdot \log(D) \end{aligned} \quad (9)$$

Analysis IV

$$\begin{aligned}
\log(N) = & m_0 + m_a \log(A) + m_b \log(B) + m_{ab} \log(A) \log(B) \\
& + m_c \log(C) + m_d \log(D) + m_s \log(S) \\
& + m_{ac} \log(A) \log(C) + m_{ad} \log(A) \log(D) + m_{bc} \log(B) \log(C) \\
& + m_{bd} \log(B) \log(D) + m_{cd} \log(C) \log(D) \\
& + m_{abc} \log(A) \log(B) \log(C) + m_{abd} \log(A) \log(B) \log(D) \\
& + m_{acd} \log(A) \log(C) \log(D) + m_{bcd} \log(B) \log(C) \log(D) \\
& + m_{abcd} \log(A) \log(B) \log(C) \log(D) \\
& + m_{sa} \log(S) \log(A) + m_{sb} \log(S) \log(B) \\
& + m_{sc} \log(S) \log(C) + m_{sd} \log(S) \log(D) \\
& + m_{sab} \log(S) \log(A) \log(B) + m_{sac} \log(S) \log(A) \log(C) \\
& + m_{sad} \log(S) \log(A) \log(D) + m_{sbd} \log(S) \log(B) \log(D) \\
& + m_{sabd} \log(S) \log(A) \log(B) \log(D)
\end{aligned} \tag{10}$$

Analysis V

$$\begin{aligned}
\log(N) = & m_0 + m_a \log(A) + m_b \log(B) + m_{ab} \log(A) \log(B) \\
& + m_c \log(C) + m_d \log(D) + m_s \log(S) \\
& + m_{l1} \log(L1) + m_{l2} \log(L2) + m_{l1l2} \log(L1) \log(L2) \\
& + m_{ac} \log(A) \log(C) + m_{bc} \log(B) \log(C) \\
& + m_{bd} \log(B) \log(D) + m_{cd} \log(C) \log(D) \\
& + m_{abd} \log(A) \log(B) \log(D) + m_{acd} \log(A) \log(C) \log(D) \\
& + m_{abcd} \log(A) \log(B) \log(C) \log(D) \\
& + m_{sa} \log(S) \log(A) + m_{sb} \log(S) \log(B) \\
& + m_{sc} \log(S) \log(C) + m_{sd} \log(S) \log(D) \\
& + m_{sab} \log(S) \log(A) \log(B) + m_{sac} \log(S) \log(A) \log(C) \\
& + m_{sad} \log(S) \log(A) \log(D) + m_{sbd} \log(S) \log(B) \log(D) \\
& + m_{sabd} \log(S) \log(A) \log(B) \log(D)
\end{aligned} \tag{11}$$

5.2.1.3 Results of the analyses

Analysis were carried out on the test results of table 3 and 4. Only the results of specimens which failed were taken into account (So, run outs were not taken into account).

The input file used and the direct output of the analyses are given in appendix A. These output files in appendix A give:

- the multiple regression format (dependent and independent variables)
- the model fitting results (coefficients, standard error of the coefficients, t-values and significance levels)
- the variance of the full regression (sum of squares, degrees of freedom, mean squares, F-ratio and P-value)
- residual summary (e.g. residual standard error)

The significance level of the coefficients is a measure for the contribution of that variable to the regression model. A low value means that the variable is important for the model used. In general a value of 0.05 is taken as a limiting value.

Table 5 summarizes the coefficients and the significance level for all the five analyses.

5.2.2 Evaluation of the analyses

The direct evaluation of the regression analyses based on the results given in appendix A and summarized in table 5 (Overview coefficients and significance levels) results in the following remarks for the five analyses:

Analysis I (the most simple model)

shows that there are a number of parameters not significant (sig > 0.05) for the simple regression model. As the basic parameters are used in this analysis we have taken them into account in all further analyses.

Analysis II (the simple model combined with the laboratory effects)
shows that the laboratory effect is not significant for that model. Therefore the laboratory effects are not taken into account in analyses III and IV.

Analysis III (no laboratory effect and no interactions with the load range, all further parameters and possible interactions taken into account)
appears to be a good model with all parameters used significant and is relatively simple having one slope for all groups.

Analysis IV (no laboratory effect, all further parameters and possible interactions taken into account)
shows that this more complex model has a number of parameters which are not significant.

Analysis V (with laboratory effect, all further parameters and possible interactions taken into account)
shows that this model has also a number of parameters which are not significant. The laboratory effect shows to be significant in this model, however this effect is confounded with the parameters AD, ABC and BCD, so that the effect can not be separated (it turned out that IV and V give exactly the same results).

From this remarks analysis III seems to be a good compromise between simplicity and complexity, giving a model with all parameters used being significant.

A further comparison is made with the help of a MATHCAD calculation for each analysis. These calculations are presented in appendix B. For each analysis the following items are covered:

- page 1 - input of parameters
- page 2 - regression coefficients and equations for the regression lines (mean line and design line (mean minus two standard deviations)) (equations)
- page 3 - number of cycles for each group at 0.60 , 0.42 and 0.30 load level (values)
 - slope and constant in S-N curve (equations)
 - level at two million cycles (equations)
- page 4 - slope, N at 0.42 level and level at two million cycles (values)
 - influencing factor air/water at 0.42 level
- page 5 - influencing factor pretreatment at 0.42 level
 - relative influencing factor for specimen type at 0.42 level
- page 6 - S-N plot of test results with mean and design line for group 1 to 8
- page 7 - S-N plot of test results with mean and design line for group 9 to 16

The S-N curve results are summarized in table 6 and figure 2. The final results as presented in appendix B of analysis IV and V are exactly the same.

The following remarks based on figure 2 can be made for each group of specimens:

Group 1 (figure 2-1a and 2-1b)

- Mean lines of analysis I, II and III are the same and through the data points.
- Slope of analysis IV/V is incorrect due to lack of experimental information.
- One data point out of five is below the design line of analysis III.

Group 2 (figure 2-2a and 2-2b)

- Mean lines of analysis I, and II are above the data points.
- Mean line of analysis III is through the data points.
- Slope of analysis IV/V is incorrect due to lack of experimental information.
- No data points are below the design line of analysis III.

Group 3 (figure 2-3a and 2-3b)

- All mean lines are through the data points.
- Slope of analysis IV/V is correct and slope of analyses I, II and III is too flat.
- No data points are below the design line of analysis III.

Group 4 (figure 2-4a and 2-4b)

- All mean lines are through the data points.
- All slopes are in agreement with the data points.
- No data points are below the design line of analysis III.

Group 5 (figure 2-5a and 2-5b)

- Mean lines of analysis I, and II are above the data points.
- Mean line of analysis III is through the data points.
- Slope of analysis IV/V is incorrect due to lack of experimental information.
- No data points are below the design line of analysis III.

Group 6 (figure 2-6a and 2-6b)

- Mean lines of analysis I, and II are above the data points.
- Mean line of analysis III is through the data points.
- Slope of analysis IV/V is incorrect due to lack of experimental information.
- No data points are below the design line of analysis III.

Group 7 (figure 2-7a and 2-7b)

- All mean lines are through the data points.
- Slope of analysis IV/V is correct and slope of analyses I, II and III is a little too steep.
- No data points are below the design line of analysis III.
- The run outs (not in the analysis) indicate a fatigue limit.

Group 8 (figure 2-8a and 2-8b)

- Mean lines of analyses III and IV/V are through the data points, while mean lines of I and II are on the low side.
- Slope of analysis IV/V is correct and slope of analyses I, II and II is too steep.
- One data point is below the design line of analysis III.

Group 9 (figure 2-9a and 2-9b)

- Mean lines of analyses III and IV/V are through the data points, while mean lines of I and II are too low.
- No data points are below the design line of analysis III.
- The experimental results from this group are far outside the normal scatter band of the total experimental results. Therefore this results looks unrealistic and an experimental error is likely.

Group 10 (figure 2-10a and 2-10b)

- Mean lines of analyses II, III and IV/V are through the data points, while mean line of I is on the high side.
- No data points are below the design line of analysis III.

Group 11 (figure 2-11a and 2-11b)

- Mean lines of analyses III and IV/V are through the data points, while mean lines of I and II are on the high side.
- All slopes are in agreement with the data points.
- No data points are below the design line of analysis III.

Group 12 (figure 2-12a and 2-12b)

- All mean lines are through the data points.
- All slopes are in agreement with the data points.
- No data points are below the design line of analysis III.

Group 13 (figure 2-13a and 2-13b)

- All mean lines are through the data points.
- No data points are below the design line of analysis III.

Group 14 (figure 2-14a and 2-14b)

- All mean lines are through the data points.
- All slopes are in agreement with the data points.
- No data points are below the design line of analysis III.

Group 15 (figure 2-15a and 2-15b)

- All mean lines are through the data points.
- Slope of analysis IV/V is correct and slope of analyses I, II and III is a little too steep.
- No data points are below the design line of analysis III.
- The run outs (not in the analysis) indicate a fatigue limit.

Group 16 (figure 2-16a and 2-16b)

- Mean lines of analyses II, III and IV/V are through the data points, while mean line of I is on the high side.
- All slopes are in agreement with the data points.
- No data points are below the design line of analysis III.
- The run outs (not in the analysis) indicate a fatigue limit.

Summarizing the most important remarks mentioned above gives:

- The mean line of analysis III is always through the data points.
- The slope of analysis III is in agreement with the experimental data of five groups (4, 11, 12, 14 and 16).
- The slope of analysis III is too flat for one group (3), too steep for one group (8) and a little too steep for two groups (7 and 15).
- For seven groups (1, 2, 5, 6, 9, 10 and 13) no experimental slope information was available.
- Two data points out of 118 are below the analysis III design line.

So, this supports the earlier statement that analysis III is a good choice for the final results.

The **influencing factor of air to water** was determined in the MathCad analyses in appendix B by dividing the number of cycles at the 0.42 level of specimen tested in air by the number of cycles of specimen tested in water. The results are summarized in table 7.

For analysis I the influence is the same for all combinations. This is due to the simple model, which can not discriminate between the various combinations. The air results are approximately a factor 2 better. Analysis II gives a more complicated picture, as can be seen in the table. Analysis III showed that in two cases the water results were slightly in favour of the air results, while the other combinations showed that air results are better. Analysis IV/V showed a more pronounced picture than III (Again the results with group 9 looks unrealistic). Without further experimental results there is no general conclusion possible.

The **influencing factor of pretreatment (D/CC)** was determined in the same way as for air/water (see table 8). The influence varies for the various analyses. Without further experimental results there is no general conclusion possible.

The **relative influencing factor for the specimen type** is determined by comparing the result of a group of specimens with all the specimens tested under the same conditions. So, for group 1 the influencing factor was determined as follows:

$$\text{Specimen factor group 1} = \frac{4 * N_{gr1}}{N_{gr1} + N_{gr5} + N_{gr9} + N_{gr13}} \quad (12)$$

The influence varies for the various analyses (see table 9). Without further experimental results there is no general conclusion possible.

5.3 Final classification

The final results based on this limited number of tests will be taken from the statistical analysis III, being a good compromise between simplicity and complexity. This analysis is carried out with the following conditions:

- multi linear regression with $\log(N)$ as the dependant variable
- one slope of the S-N curve for all groups of specimens (no interaction with the load level S in the statistical analysis)
- run out test results are not taken into account

The results are classified by the relative load level at two million cycles ($\Delta F / FS_{N=2 \cdot 10^6}$) (see appendix B page 4 of analysis III). A graphical presentation of the results is given in figure 3. With a rounding off of the results in classes of 0.02 the classification in table 10 is get. The range of classes is from 0.16 to 0.24, with group 9 as an exception being 0.40.

The difference in load level for the various groups can be compared with the difference in life time given in table 7, 8 and 9. It has to be noticed that a factor of 1.1 in load level corresponds with a factor of 1.83 in life time ($1.1^{6.364} = 1.83$).

The classification presented here has to be treated as being the direct result of the statistical analysis of the test results mentioned. For a code classification a more general evaluation is needed.

The experimental programme and the statistical analysis was based on the relative fatigue load ($\Delta F / FS$). It is possible that other parameters are governing the fatigue behaviour (e.g. :stress range in the plates, shear stress in the bonding material, cover plate length, etc.) and that a re-analysis based on other parameters is needed.

6 CONCLUSIONS

Fatigue tests were carried out on 16 groups of aluminium bonded joints in strips with a thickness of 6 mm.

A statistical analysis with a multi regression technique was carried out on the test results.

A model with one slope for all the 16 groups proved to be adequate, however for seven groups no experimental slope information was available.

One group (9) gives unrealistic high results compared to the rest of the results.

For the other groups a design line classification based on the relative fatigue load ($\Delta F/F_s$) at 2 million cycles is given. The classification ranges from 0.16 to 0.24 (see table 10).

In general water has little or a slightly negative influence on the life time and the chromate based conversion pretreatment has little or a positive influence on life time.

TABLES

Table 1 Test programme

A alloy	B adhe- sive	C pre- treat- ment	D envi- ron- ment	Small specimen programme		Group number
				nr of specimen	laboratory	
6061-T6	9323	D	air	4	Alcan (3)	1
			water	4	Porto (2)	2
		CC	air	12	BNF/TWI (4)	3
			water	12	Pechiney (1)	4
	7823	D	air	4	BNF/TWI (4)	5
			water	4	Pechiney (1)	6
		CC	air	12	Alcan (3)	7
			water	12	Porto (2)	8
5754-WH	9323	D	air	4	Pechiney (1)	9
			water	4	BNF/TWI (4)	10
		CC	air	12	Porto (2)	11
			water	12	Alcan (3)	12
	7823	D	air	4	Porto (2)	13
			water	4	Alcan (3)	14
		CC	air	4	Pechiney (1)	15
			water	4	BNF/TWI (4)	16

Table 2 Test specimen

alloy	adhesive	total length L_t	thick- ness T	width W	length cover plates L_c	yield strength material σ_y	shear stress at yield load τ
6061- T6	9323	360	6.35	24	72	240	21.2
	7823	360	6.35	24	50	240	30.5
5754- WH	9323	360	6.0	24	40	140	21.0
	7823	360	6.0	24	30	140	30.0

Table 3 a Test results

A Alloy	B adhesive	C pre-treatment	D environment	lab	level 0.60		level 0.42		level 0.30	
					Spec.No.	cycles	Spec.No.	cycle	Spec.No.	cycles
6061 - T6	9323	D	air	Al	ASa06-01 / 05 see table 4					
			water	Po			ASe06-03 C ASe06-04 C ASe06-05 C ASe06-06 C	28360 15010 22290 16340		
		CC	air	BN	ASc06-05 C ASc06-06 C ASc06-07 C ASc06-08 C	9500 27610 14260 57290	ASc06-09 C ASc06-10 C ASc06-11 C ASc06-12 C	82520 53610 71200 35710	ASc06-13 C ASc06-14 C ASc06-15 C ASc06-16 C	293600 390200 145100 436000
	7823	D	air	BN			ASb06-03 C ASb06-04 C ASb06-05 C ASb06-06 C	33080 51670 21310 4620		
		CC	water	Py	ASg06-05 C ASg06-06 C ASg06-07 C ASg06-08 C	6290 5580 10280 6300	ASg06-09 C ASg06-10 C ASg06-11 C ASg06-12 C	73630 62130 59700 19500	ASg06-13 C ASg06-14 C ASg06-15 C ASg06-16 C	224040 >10 ⁷ 176480 622750
		CC	air	Al	ASd06-01 / 10 see table 4					
			water	Po	ASh06-05 C ASh06-06 C ASh06-07 C ASh06-08 C	7490 4920 8090 1690	ASh06-09 C ASh06-10 C ASh06-11 C ASh06-12 C	43890 27100 53840 69740	ASh06-13 C ASh06-14 C ASh06-15 C ASh06-16 C	7011290 7769970 5674200 4826330

Al = Alcan; Po = Porto; BN = BNF/TWI; Py = Pechiney

Table 3 b Test results (continued)

A Alloy	B adhesive	C pre-treatment	D environment	lab	level 0.60		level 0.42		level 0.30	
					Spec.No.	cycles	Spec.No.	cycle	Spec.No.	cycles
5754 - WH	9323	D	air	Py			ASi06-03 C ASi06-04 C ASi06-05 C ASi06-06 C	7870110 >10 ⁷ 9867250 8986580		
			water	BN			ASm06-03 C ASm06-04 C ASm06-05 C ASm06-06 C	33230 111810 175060 ?		
		CC	air	Po	ASk06-05 C ASk06-06 C ASk06-07 C ASk06-08 C	15200 21070 29940 15570	Ask06-09 C Ask06-10 C Ask06-11 C Ask06-12 C	150770 311280 263240 217590	Ask06-13 C Ask06-14 C Ask06-15 C Ask06-16 C Ask06-17 C	1691210 1612230 1355500 3024060 3802780
			water	Al	ASo06-01 / 13 see table 4					
	7823	D	air	Po			ASj06-03 C ASj06-04 C ASj06-05 C ASj06-06 C	492550 816260 156640 241830		
			water	Al	ASn06-01 / 06 see table 4					
		CC	air	Py	ASl06-05 ASl06-06 ASl06-07 ASl06-08	58200 17860 20460 25670	ASl06-09 ASl06-10 ASl06-11 ASl06-12	1565900 561960 841360 195640	ASl06-13 ASl06-14 ASl06-15 ASl06-16	>10 ⁷ >10 ⁷ >10 ⁷ >10 ⁷
			water	BN	ASp06-05 ASp06-06 ASp06-07 ASp06-14 ASp06-17	7790 18110 11890 4970 13190	ASp06-09 ASp06-10 ASp06-11 ASp06-12	127400 220470 29870 137020	ASp06-13 ASp06-15 ASp06-16 ASp06-18	382000 >21*10 ⁶ 1187000 >12*10 ⁶

Al = Alcan; Po = Porto; BN = BNF/TWI; Py = Pechiney

Table 4 Alcan test results

A Alloy	B adhesive	C pre-treatment	D environment	Spec.No.	level	cycle
6061-T6	9323	D	air	ASa06-01	0.37	295214
				ASa06-02	0.33	16727
				ASa06-03	0.43	330274
				ASa06-04	0.43	98648
				ASa06-05	0.32	358066
	7823	CC	air	ASd06-01	0.13	>11769161
				ASd06-02	0.25	>13017314
				ASd06-03	0.30	>11027020
				ASd06-04	0.33	1219667
				ASd06-05	0.34	483198
				ASd06-06	0.37	190606
				ASd06-07	0.39	150788
				ASd06-08	0.42	81516
				ASd06-09	0.44	32007
				ASd06-10	0.54	17361
5754-WH	9323	CC	water	ASo06-01	0.27	>11367725
				ASo06-02	0.67	10615
				ASo06-03	0.49	17805
				ASo06-04	0.58	11693
				ASo06-05	0.49	56414
				ASo06-06	0.40	324738
				ASo06-07	0.36	1402156
				ASo06-08	0.60	15401
				ASo06-09	0.54	40934
				ASo06-10	0.71	13818
				ASo06-11	0.45	72143
				ASo06-12	0.80	4120
				ASo06-13	0.31	387618
	7823	D	water	ASn06-01	0.76	3118
				ASn06-02	0.67	10420
				ASn06-03	0.58	26085
				ASn06-04	0.42	361878
				ASn06-05	0.31	387618
				ASn06-06	0.31	>32340538

Table 5 Overview coefficients and significance levels

par.	I		II		III		IV		V	
	coef.	sig	coef.	sig	coef.	sig	coef.	sig	coef.	sig
Con	-2.10	.427	-.052	.986	-360.	.016	-179.	.224	788.	.003
A	4.84	.034	4.44	.075	398.	.002	268.	.037	-304.	.003
B	3.07	.180	2.66	.283	271.	.035	186.	.136	-285.	.008
AB	-2.60	.188	-2.22	.302	-301.	.007	-245.	.026	-7.30	.877
C	.206	.537	.238	.463	302.	.013	177.	.103	-294.	.004
D	-.986	.001	-1.05	.001	298.	.020	207.	.090	-289.	.005
S	-6.33	.000	-6.38	.000	-6.36	.000	121.	.447	121.	.447
L1	#		-0.77	.757	#		#		-74.9	.010
L2	#		-0.64	.797	#		#		-32.4	.006
L1L2	#		.024	.991	#		#		31.1	.009
AC	#		#		-327.	.002	-235.	.013	3.40	.855
AD	#		#		-325.	.004	-260.	.016	*	
BC	#		#		-232.	.027	-167.	.062	242.	.006
BD	#		#		-232.	.035	-183.	.084	-11.2	.806
CD	#		#		-253.	.016	-178.	.046	-6.51	.568
ABC	#		#		253.	.006	207.	.009	*	
ABD	#		#		253.	.009	222.	.018	222.	.018
ACD	#		#		271.	.003	215.	.006	215.	.006
BCD	#		#		201.	.026	149.	.051	*	
ABCD	#		#		-215.	.006	-177.	.008	-177.	.008
SA	#		#		#		-80.9	.547	-80.9	.547
SB	#		#		#		26.6	.856	26.7	.856
SC	#		#		#		-81.5	.038	-81.5	.038
SD	#		#		#		35.5	.785	35.5	.785
SAB	#		#		#		-38.8	.755	-38.8	.755
SAC	#		#		#		61.3	.051	61.3	.051
SAD	#		#		#		-37.7	.733	-37.7	.733
SBC	#		#		#		*		*	
SBD	#		#		#		-70.9	.553	-70.9	.553
SCD	#		#		#		*		*	
SABC	#		#		#		*		*	
SABD	#		#		#		67.7	.506	67.7	.506
SACD	#		#		#		*		*	
SBCD	#		#		#		*		*	
SABCD	#		#		#		*		*	

* not in the analysis due to confounding with other parameters

not in the analysis on purpose

Table 6 Overview slope and results (N-mean/N-design) at level 0.42

group no.	Analysis I		Analysis II		Analysis III		Analysis IV/V	
	m	N	m	N	m	N	m	N
1	6.338	67007 7395	6.380	65191 7748	6.364	66747 12032	-2.311	186669 47730
2		33823 3733		34519 4103		19843 3577	-0.663	19842 5074
3		77278 8529		50459 5997		74496 13429	3.752	73197 18716
4		39008 4305		62396 7416		49365 8898	5.4	47592 12169
5		92957 10259		58270 6926		20254 3651	2.315	20254 5179
6		46922 5178		72055 8564		26442 4766	4.255	26442 6761
7		107206 11831		104790 12455		96841 17457	8.377	87429 22355
8		54115 5972		55487 6595		115462 20813	10.317	118577 30319
9		317561 35047		511215 60761		8869991 1598900	6.242	8869978 2267997
10		160296 17691		96526 11473		86643 15618	5.176	86643 22154
11		366238 40419		393671 46790		222896 40179	6.748	221219 56564
12		184867 20402		173589 20632		161351 29085	5.681	140465 35916
13		256249 28280		286292 34027		351296 63324	8.248	351295 89824
14		129347 14275		126240 15004		162757 29339	5.628	138852 35504
15		295527 32615		517499 61508		402847 72617	8.754	616915 157741
16		149174 16463		97713 11614		96449 17386	6.133	94228 24094

Table 7 Influencing factor on life time for air/water results

Numerator group	Denominator group	Analysis I	Analysis II	Analysis III	Analysis IV/V
1	2	1.981	1.889	3.364	9.407
3	4	1.981	0.809	1.509	1.538
5	6	1.981	0.809	0.766	0.766
7	8	1.981	1.889	0.839	0.737
9	10	1.981	5.296	102.374	102.374
11	12	1.981	2.268	1.381	1.575
13	14	1.981	2.268	2.158	2.530
15	16	1.981	5.296	4.177	6.547
Σ average		1.981	2.565	14.571	15.684
Π average		1.981	2.07	2.834	3.486

Table 8 Influencing factor on life time for pretreatment D/CC results

Numerator group	Denominator group	Analysis I	Analysis II	Analysis III	Analysis IV/V
1	3	0.867	1.292	0.896	2.550
2	4	0.867	0.553	0.402	0.417
5	7	0.867	0.556	0.209	0.232
6	8	0.867	1.299	0.229	0.223
9	11	0.867	1.299	39.794	40.096
10	12	0.867	0.556	0.537	0.617
13	15	0.867	0.553	0.872	0.569
14	16	0.867	1.292	1.687	1.474
Σ average		0.867	0.925	5.578	5.772
Π average		0.867	0.848	0.926	1.017

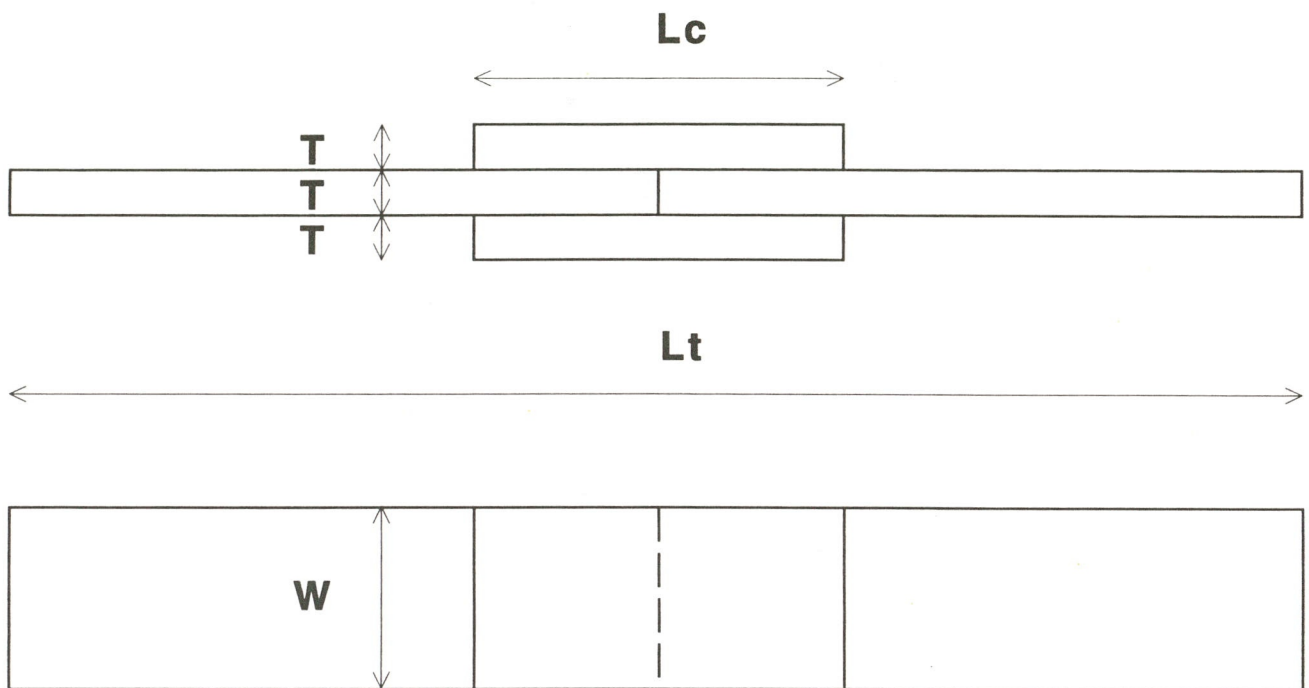
Table 9 Relative influence factor specimen on life time

Type	group nr	Analysis I	Analysis II	Analysis III	Analysis IV/V
6061 / 9323	1	0.365	0.283	0.029	0.079
	2	0.365	0.419	0.268	0.292
	3	0.365	0.189	0.374	0.293
	4	0.365	0.641	0.467	0.475
	Σ average	0.365	0.383	0.285	0.285
	Π average	0.365	0.346	0.191	0.238
6061 / 7823	5	0.507	0.253	0.009	0.009
	6	0.507	0.875	0.358	0.389
	7	0.507	0.393	0.486	0.350
	8	0.507	0.570	1.093	1.183
	Σ average	0.507	0.523	0.486	0.483
	Π average	0.507	0.472	0.202	0.193
5754 / 9323	9	1.731	2.220	3.812	3.763
	10	1.731	1.172	1.172	1.275
	11	1.731	1.477	1.119	0.886
	12	1.731	1.784	1.527	1.402
	Σ average	1.731	1.663	1.907	1.831
	Π average	1.731	1.613	1.662	1.562
5754 / 7823	13	1.397	1.243	0.151	0.149
	14	1.397	1.533	2.202	2.044
	15	1.397	1.941	2.022	2.471
	16	1.397	1.004	0.913	0.940
	Σ average	1.397	1.431	1.322	1.401
	Π average	1.397	1.388	0.885	0.917

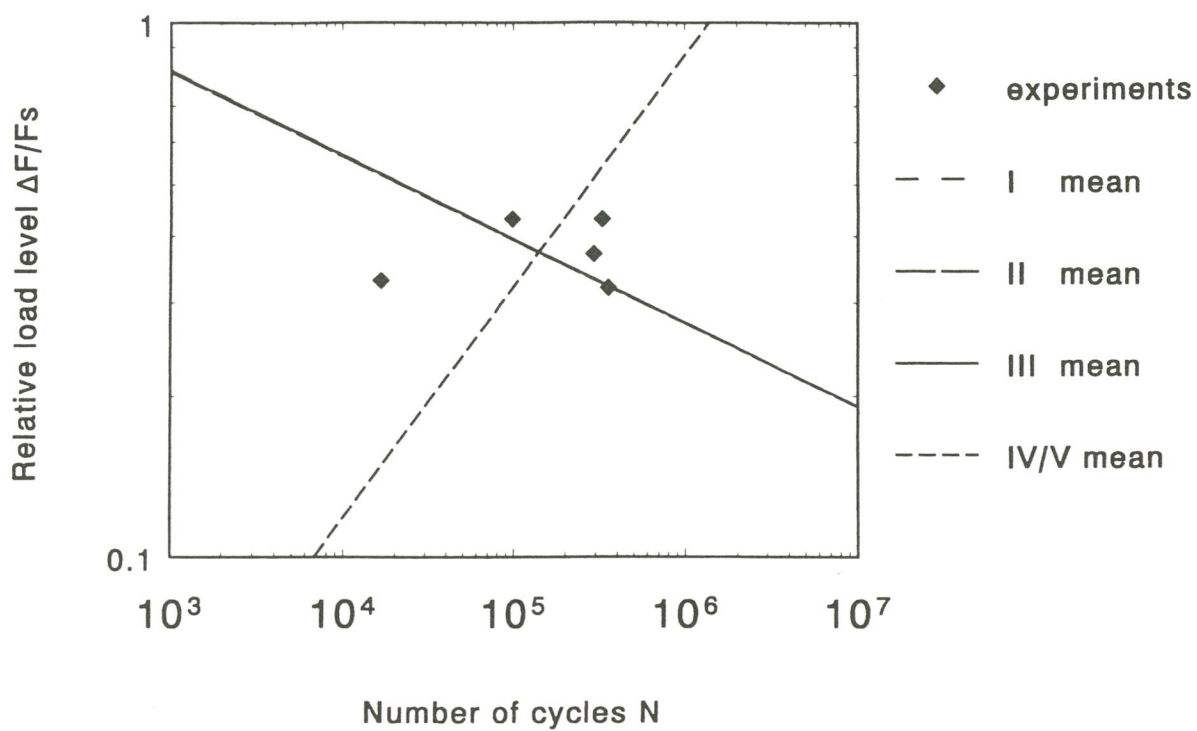
Table 10 Classification based on Analysis III

A alloy	B adhesive	C pre-treatment	D environment	Group number	Classification $\Delta F / FS_{N=2 \cdot 10^6}$
6061-T6	9323	D	air	1	0.18
			water	2	0.16
		CC	air	3	0.18
			water	4	0.18
	7823	D	air	5	0.16
			water	6	0.16
		CC	air	7	0.20
			water	8	0.20
5754-WH	9323	D	air	9	0.40
			water	10	0.20
		CC	air	11	0.22
			water	12	0.22
	7823	D	air	13	0.24
			water	14	0.22
		CC	air	15	0.24
			water	16	0.20

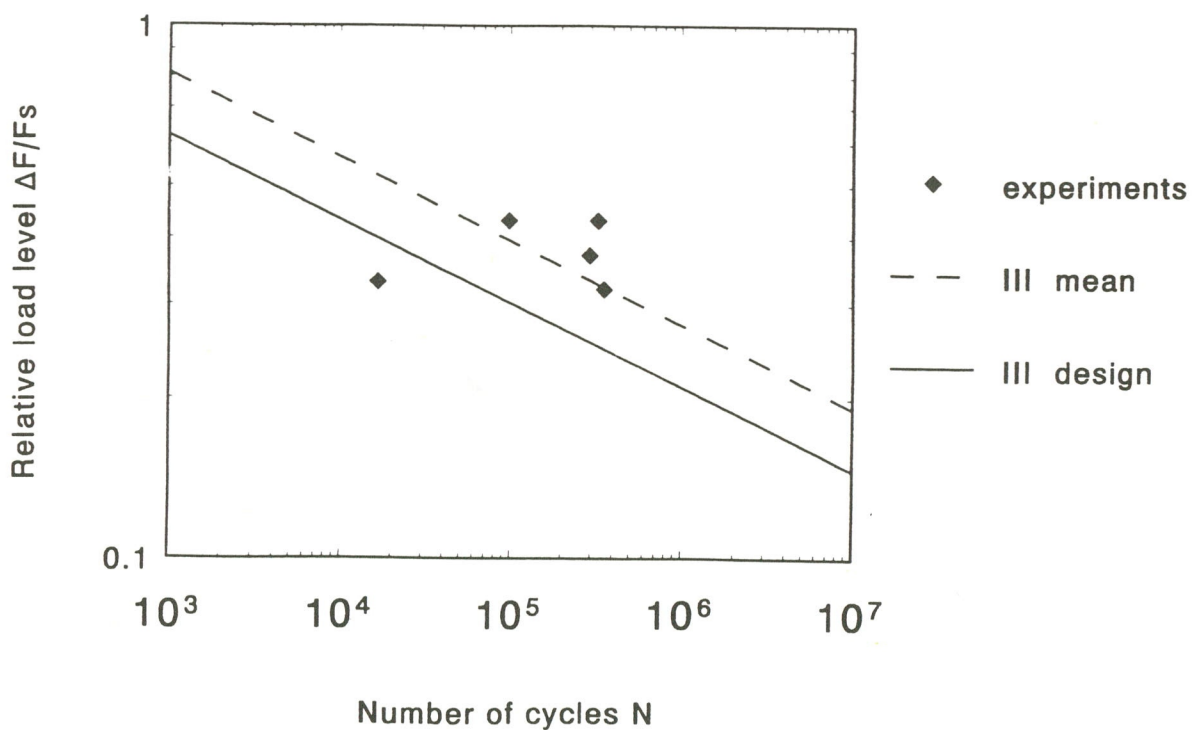
FIGURES



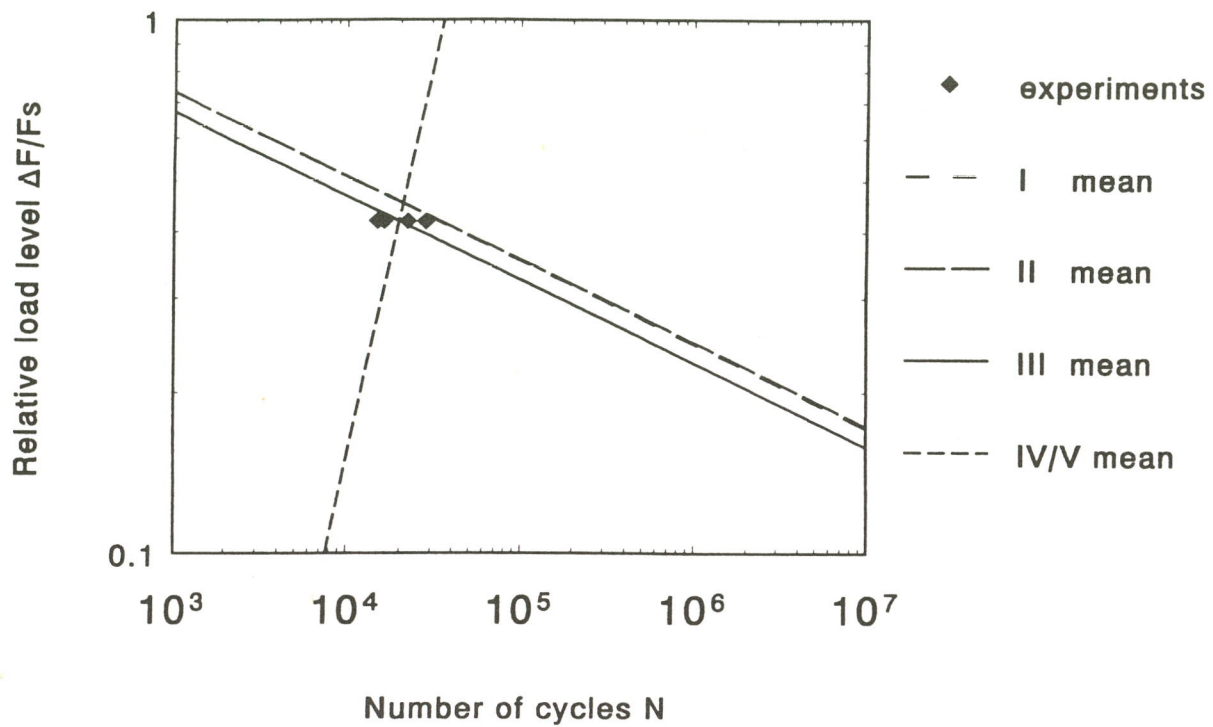
1 Test specimen for adhesive bonded joints



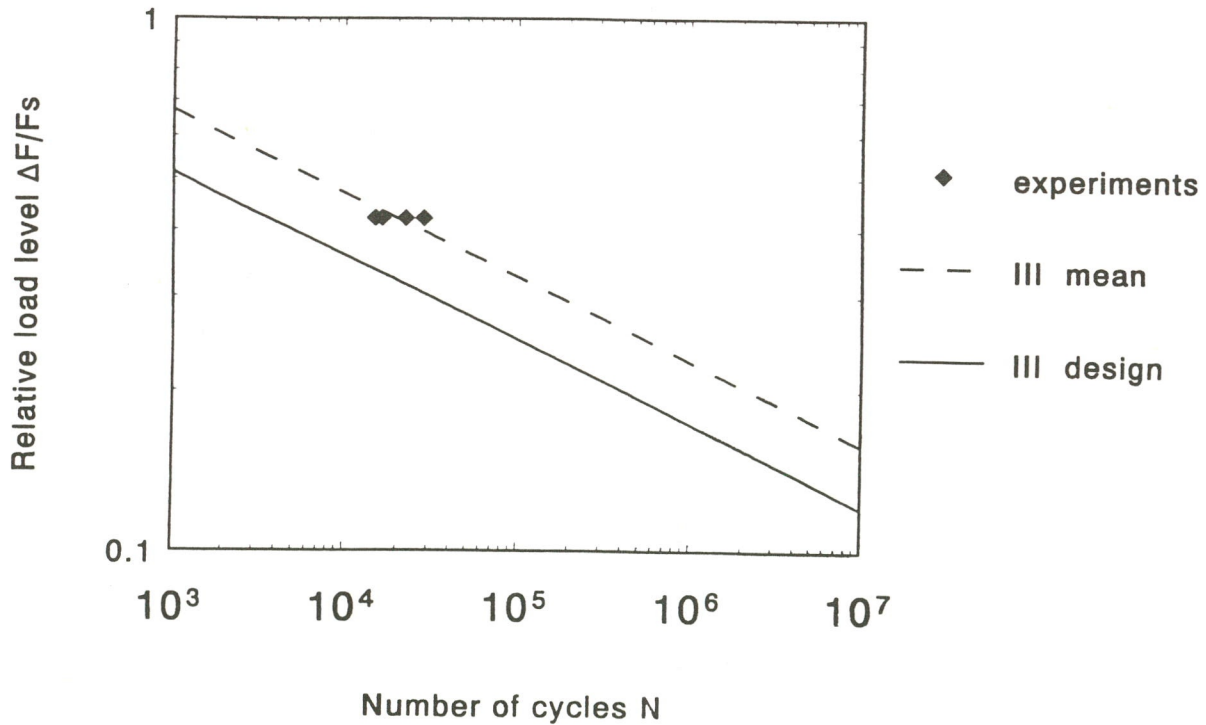
2- 1a Mean S-N curves group 1 (analyses I, II, III and IV/V)



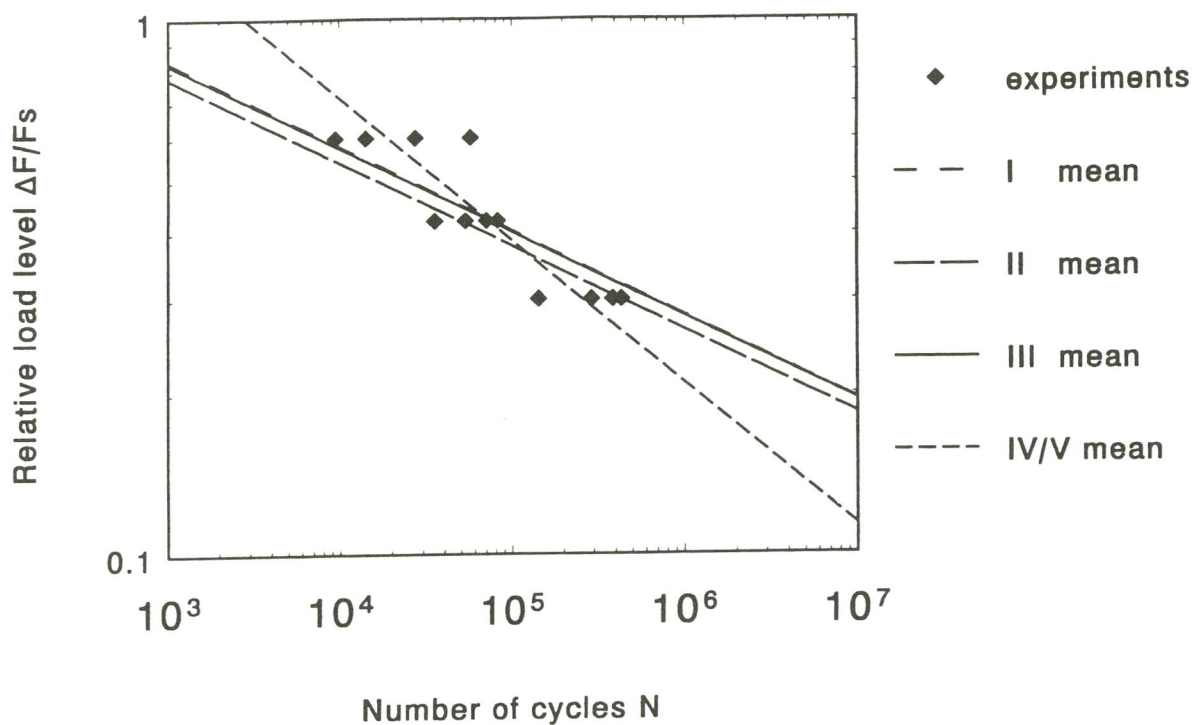
2- 1b Recommended mean and design S-N curve group 1 (analysis III)



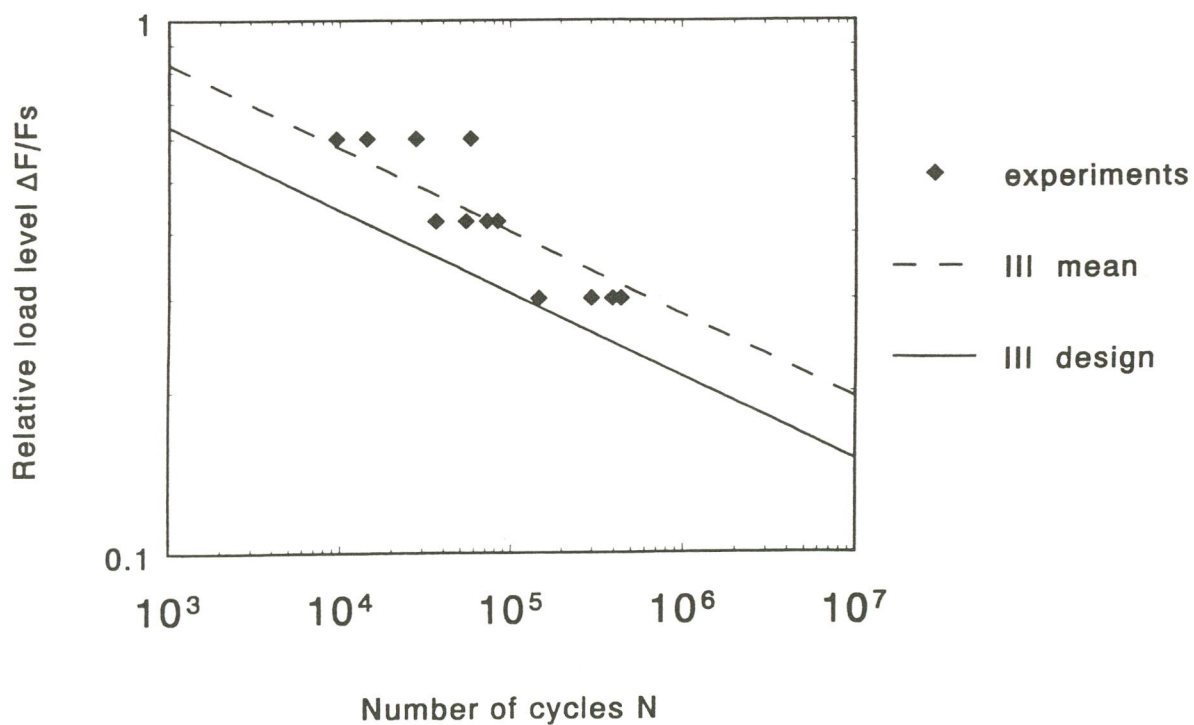
2- 2a Mean S-N curves group 2 (analyses I, II, III and IV/V)



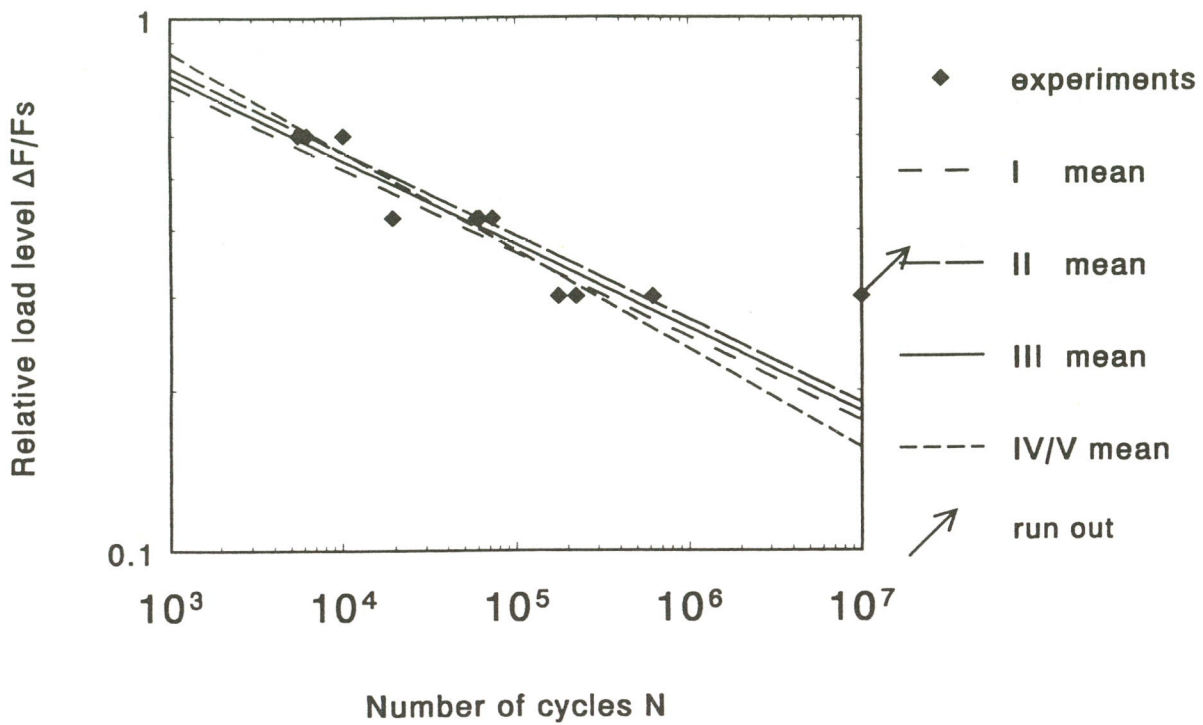
2- 2b Recommended mean and design S-N curve group 2 (analysis III)



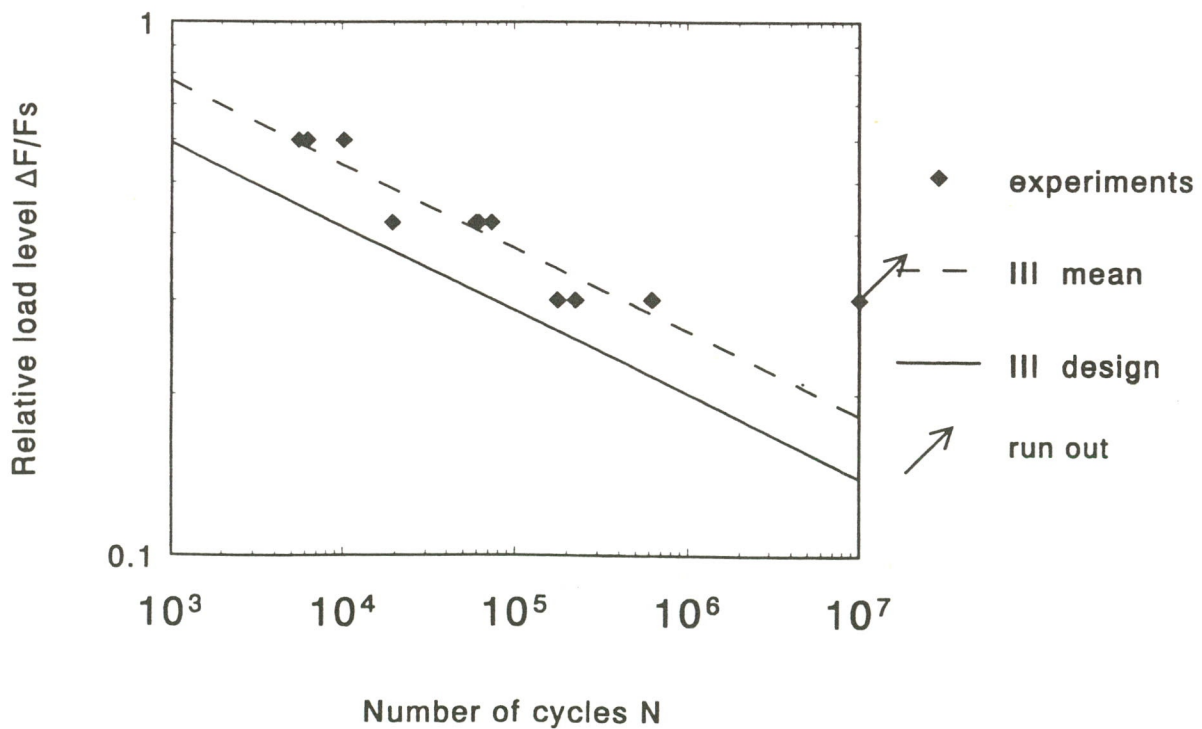
2- 3a Mean S-N curves group 3 (analyses I, II, III and IV/V)



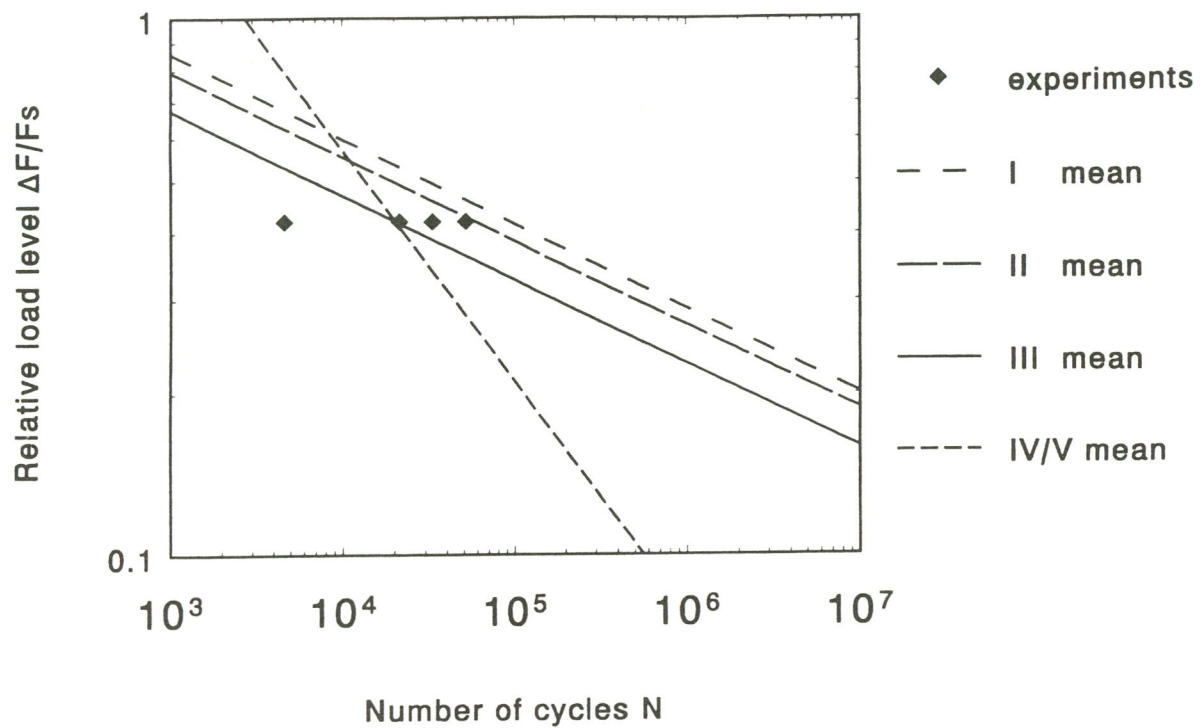
2- 3b Recommended mean and design S-N curve group 3 (analysis III)



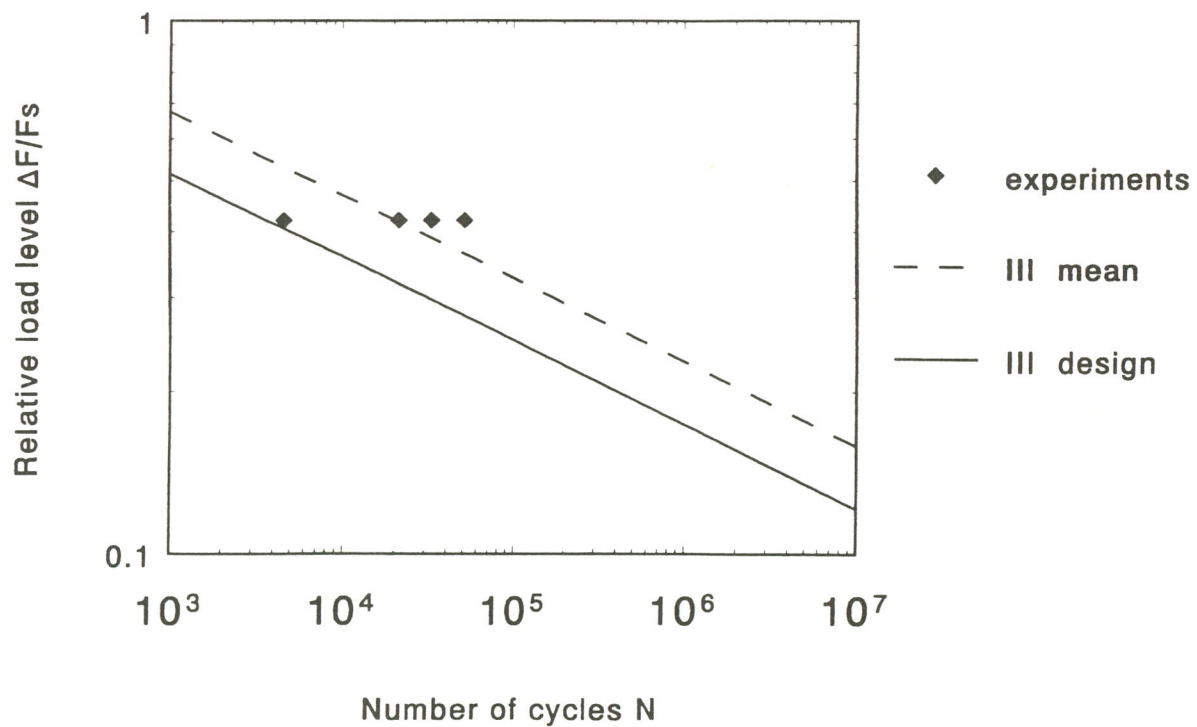
2- 4a Mean S-N curves group 4 (analyses I, II, III and IV/V)



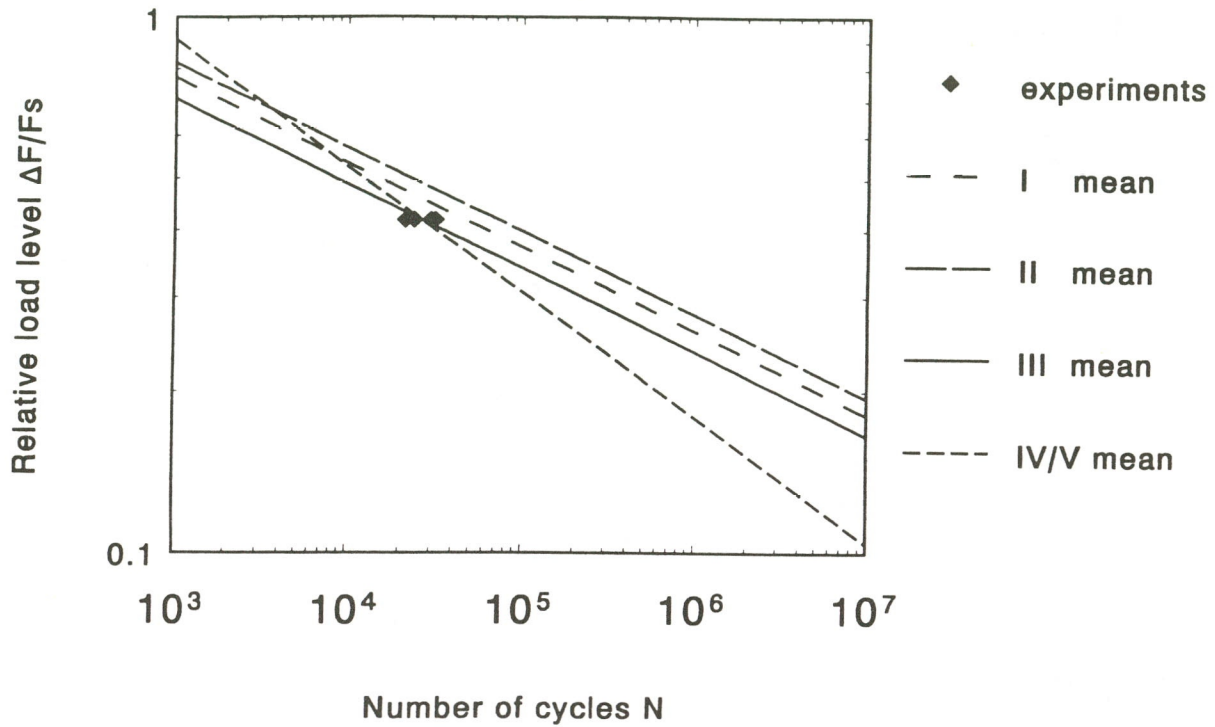
2- 4b Recommended mean and design S-N curve group 4 (analysis III)



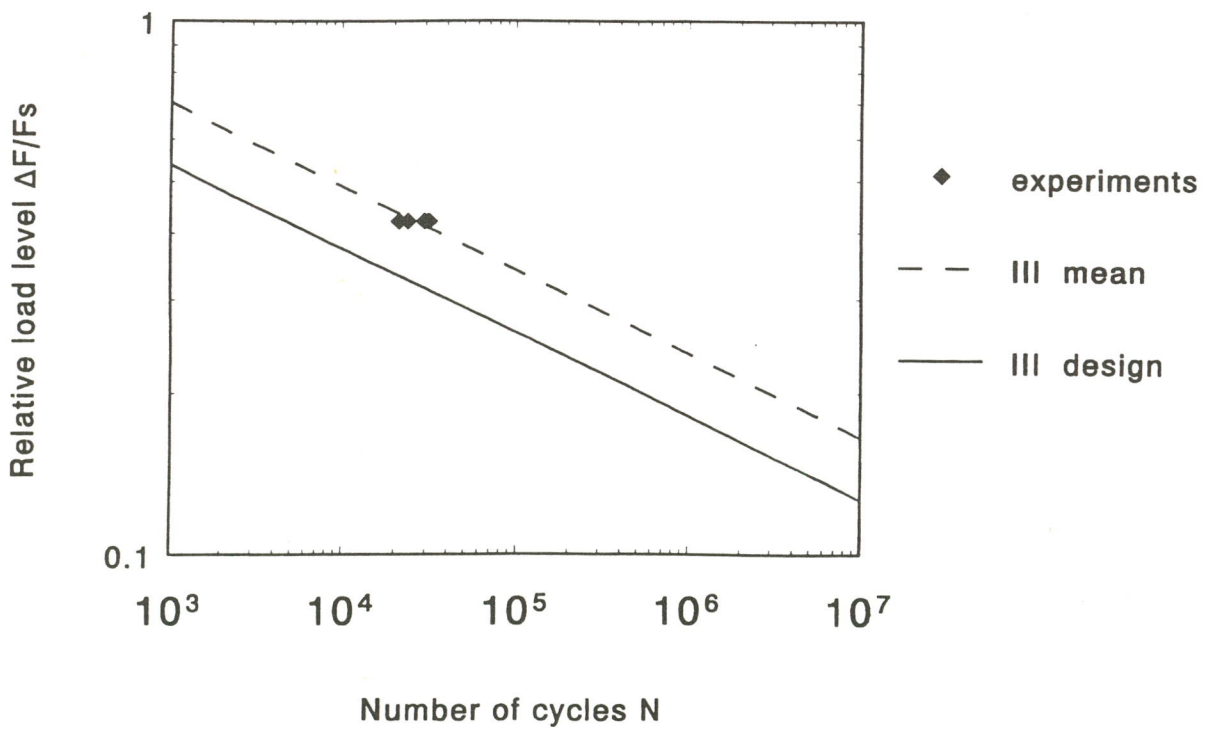
2- 5a Mean S-N curves group 5 (analyses I, II, III and IV/V)



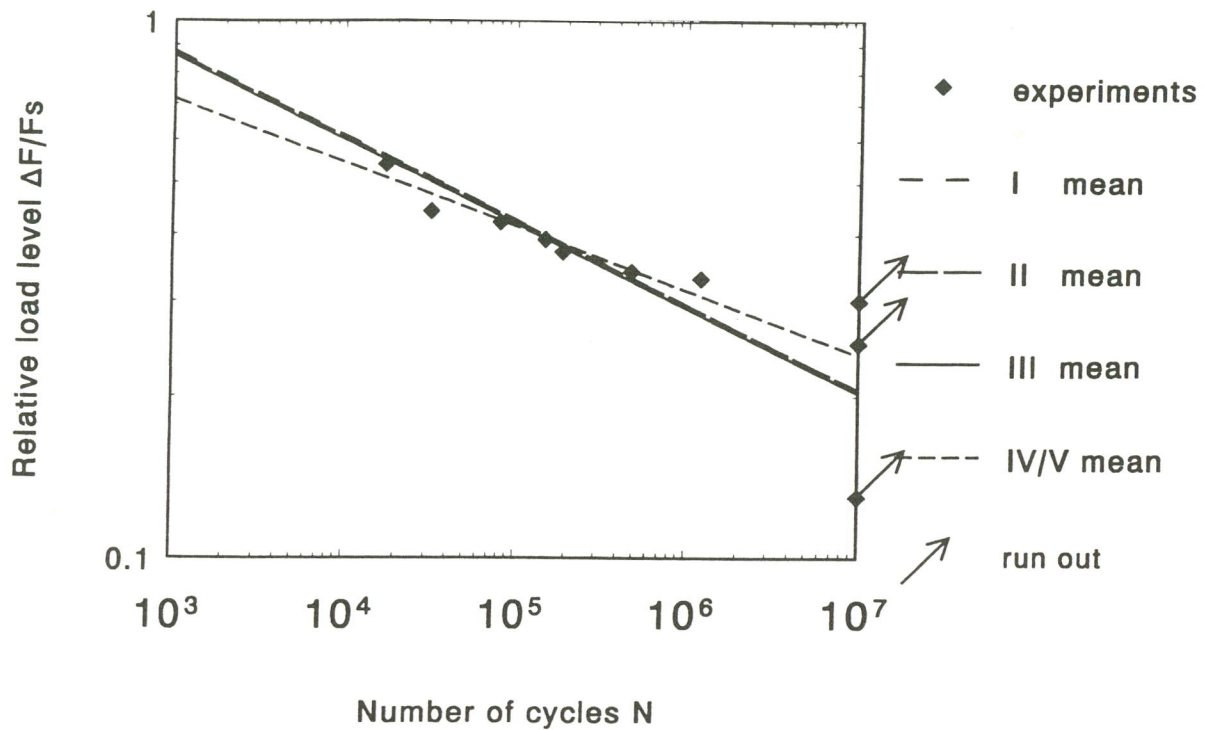
2- 5b Recommended mean and design S-N curve group 5 (analysis III)



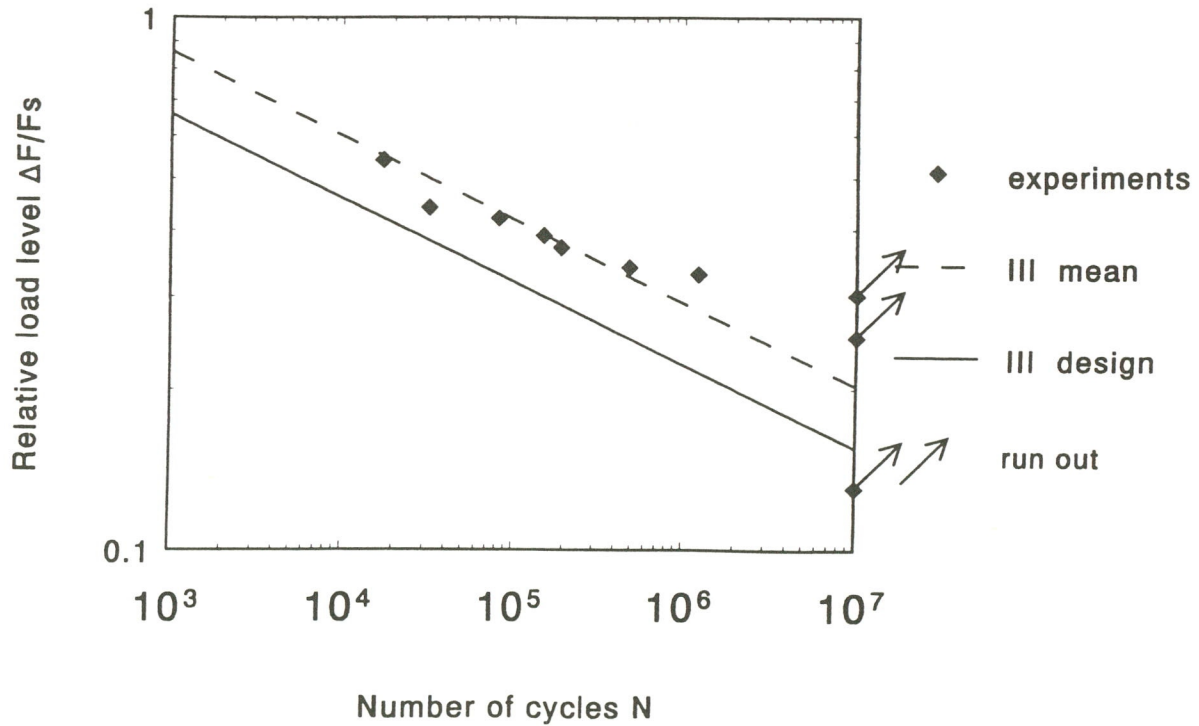
2- 6a Mean S-N curves group 6 (analyses I, II, III and IV/V)



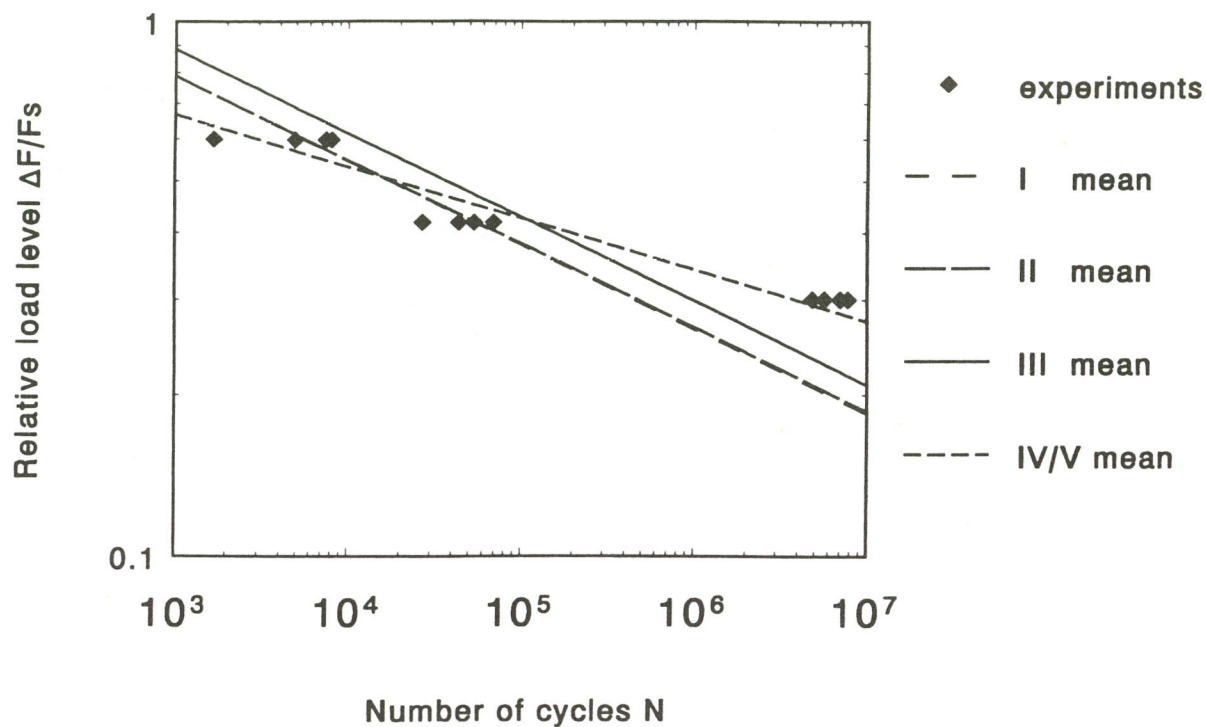
2- 6b Recommended mean and design S-N curve group 6 (analysis III)



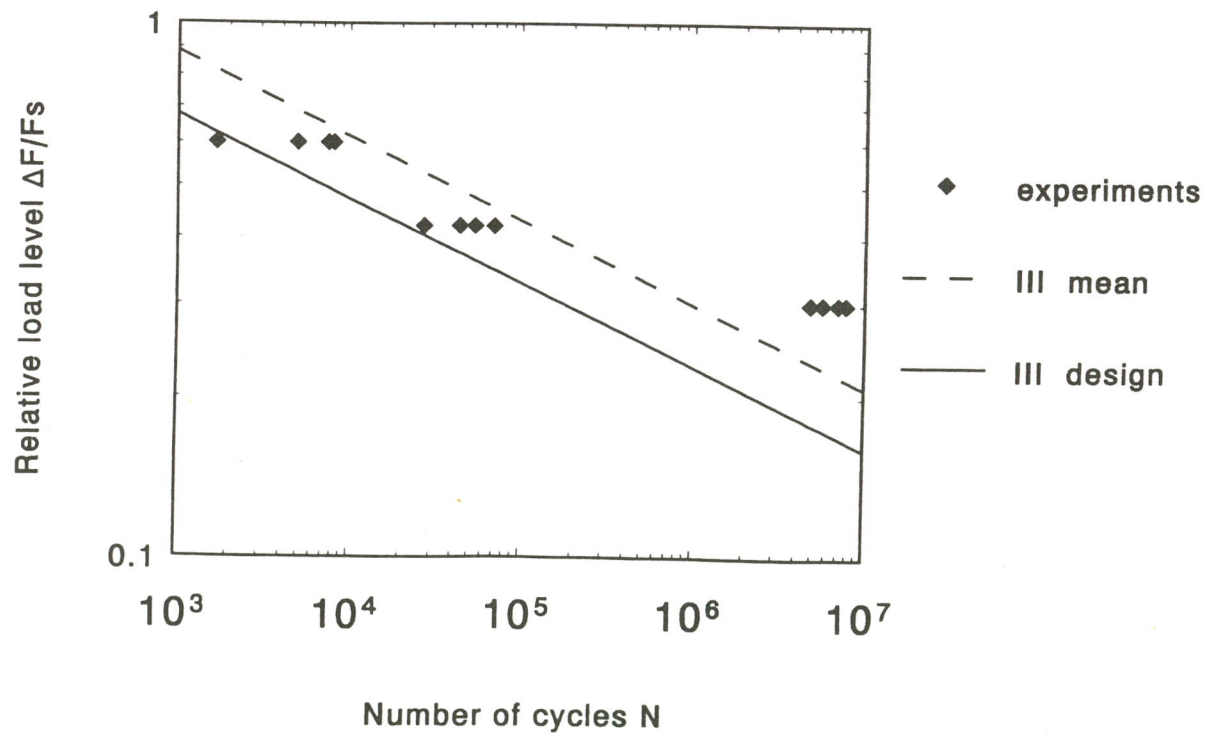
2- 7a Mean S-N curves group 7 (analyses I, II, III and IV/V)



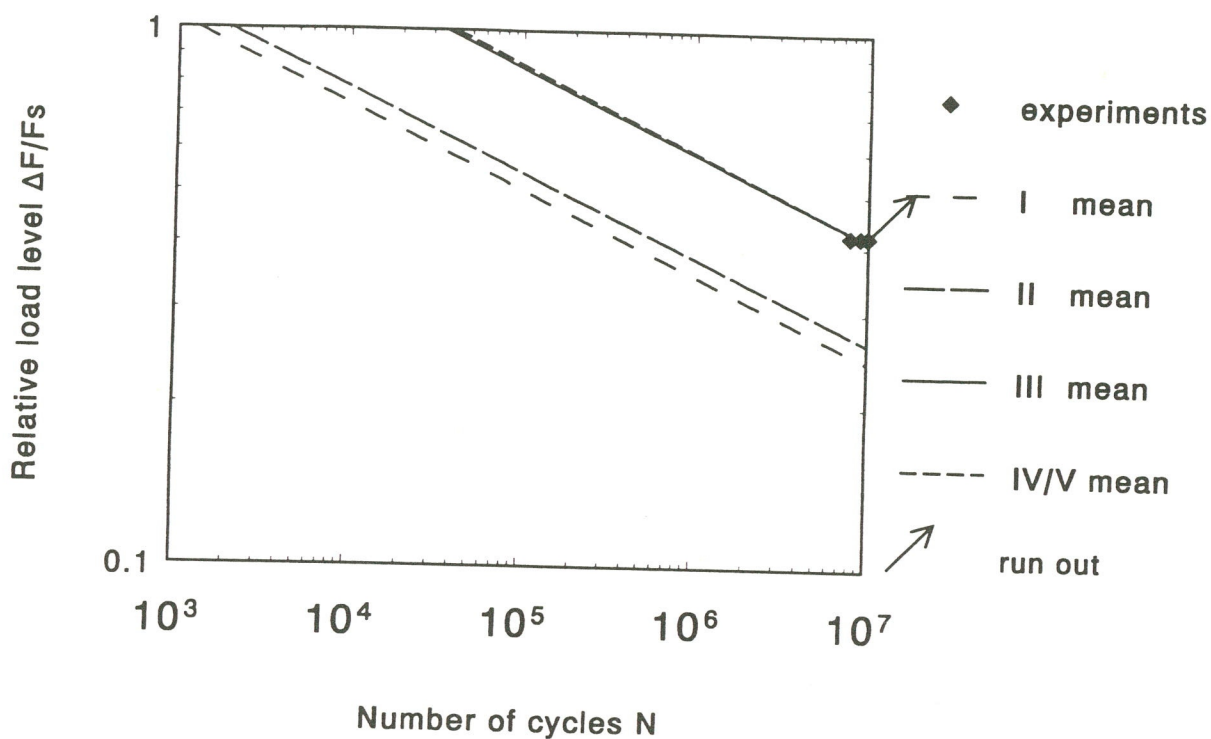
2- 7b Recommended mean and design S-N curve group 7 (analysis III)



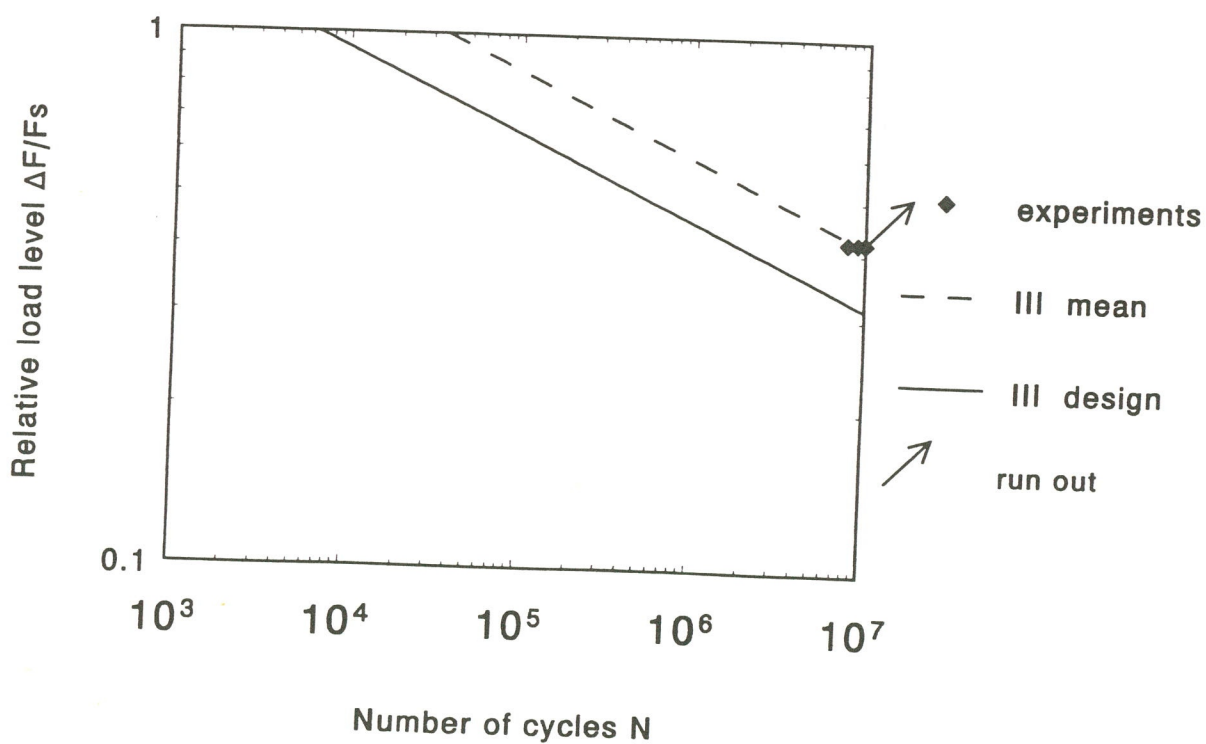
2- 8a Mean S-N curves group 8 (analyses I, II, III and IV/V)



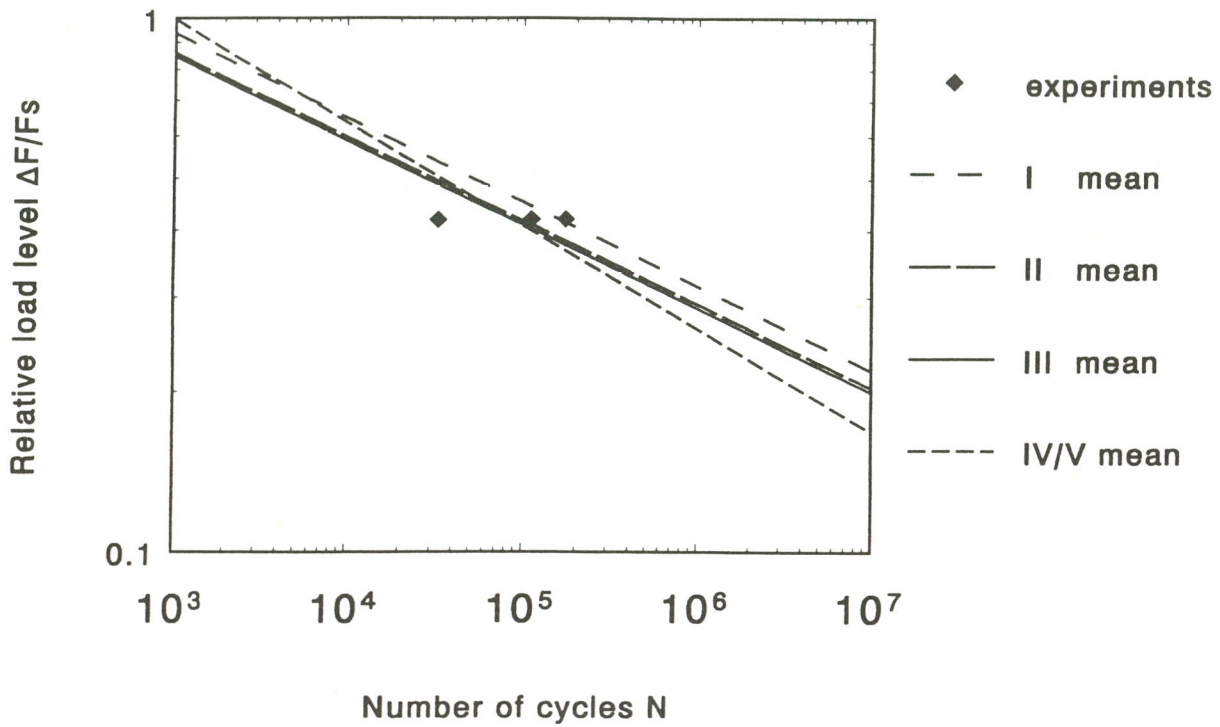
2- 8b Recommended mean and design S-N curve group 8 (analysis III)



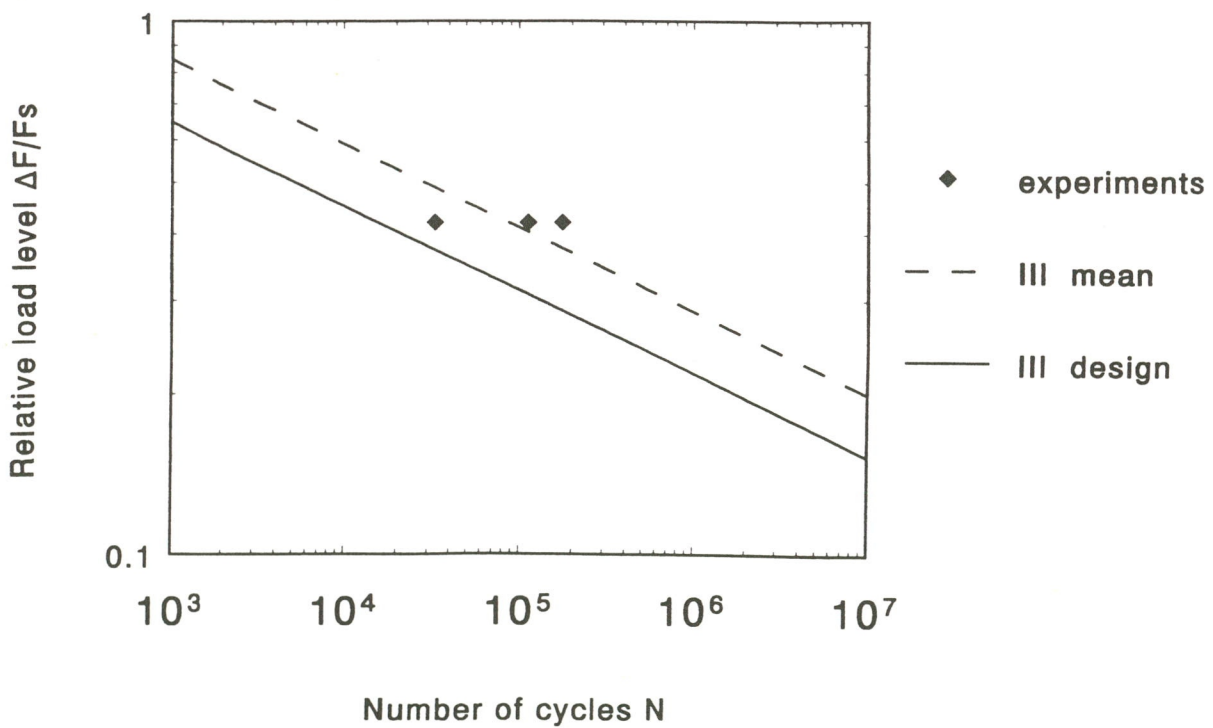
2- 9a Mean S-N curves group 9 (analyses I, II, III and IV/V)



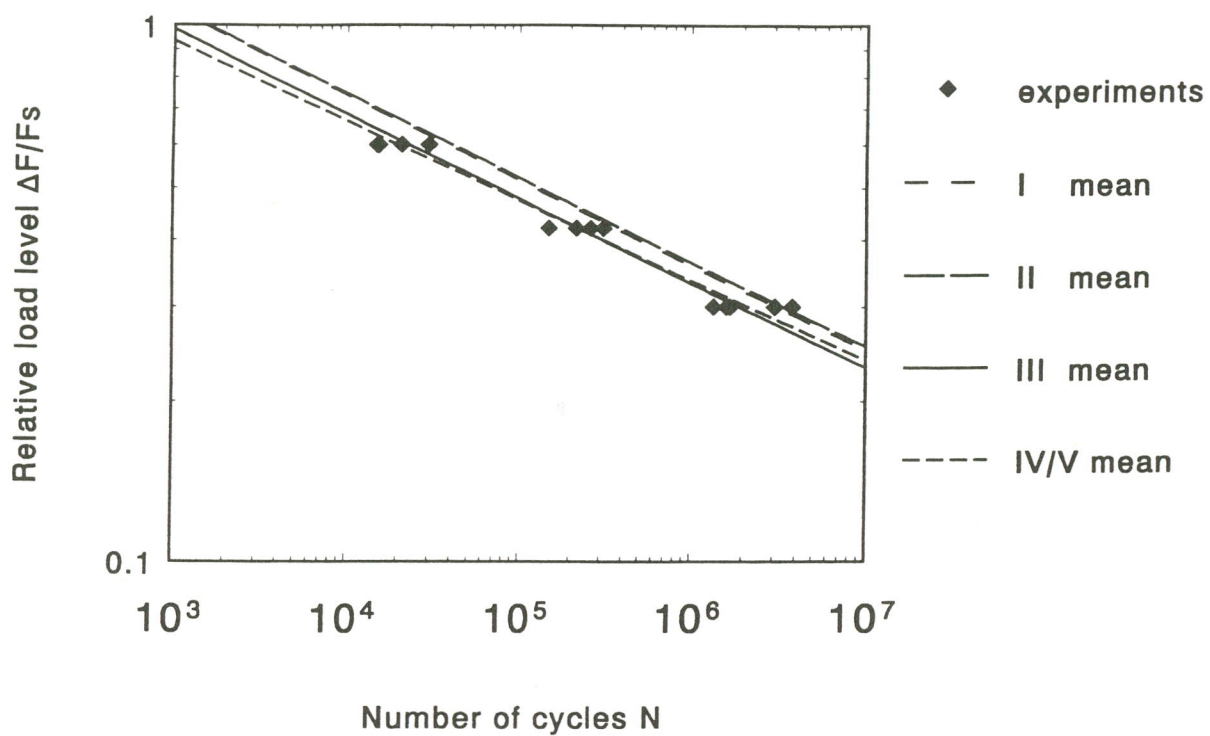
2- 9b Recommended mean and design S-N curve group 9 (analysis III)



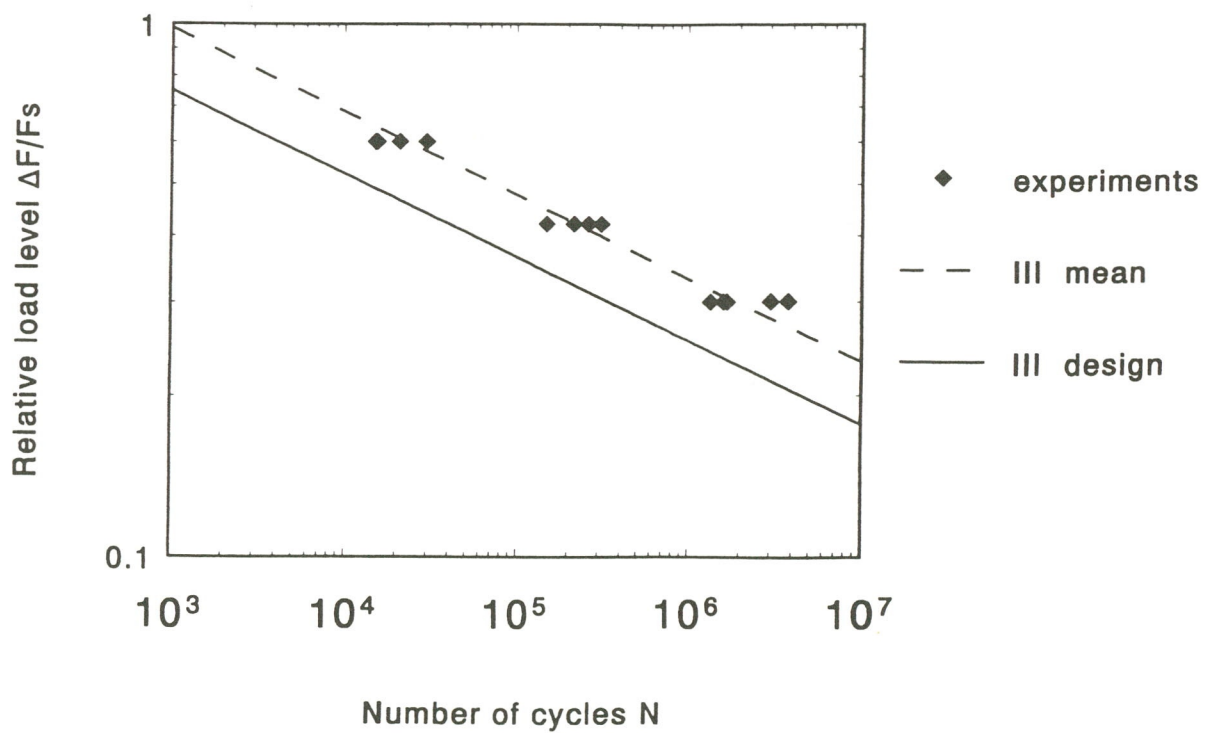
2- 10a Mean S-N curves group 10 (analyses I, II, III and IV/V)



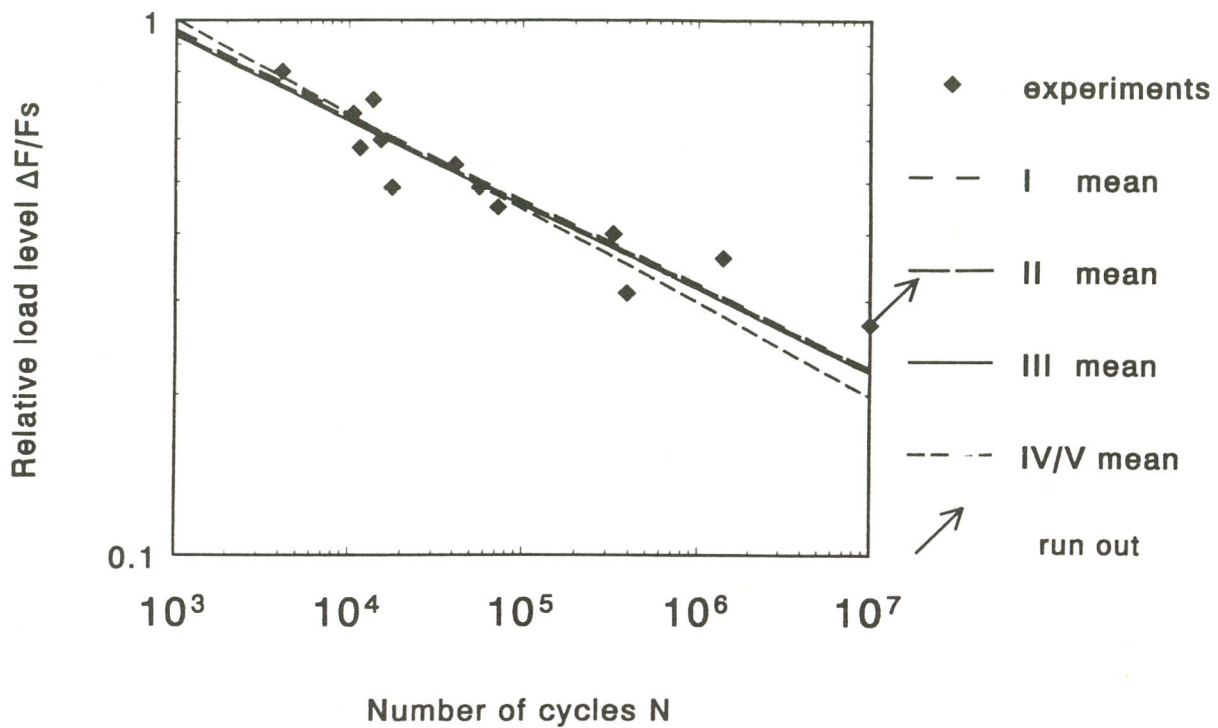
2- 10b Recommended mean and design S-N curve group 10 (analysis III)



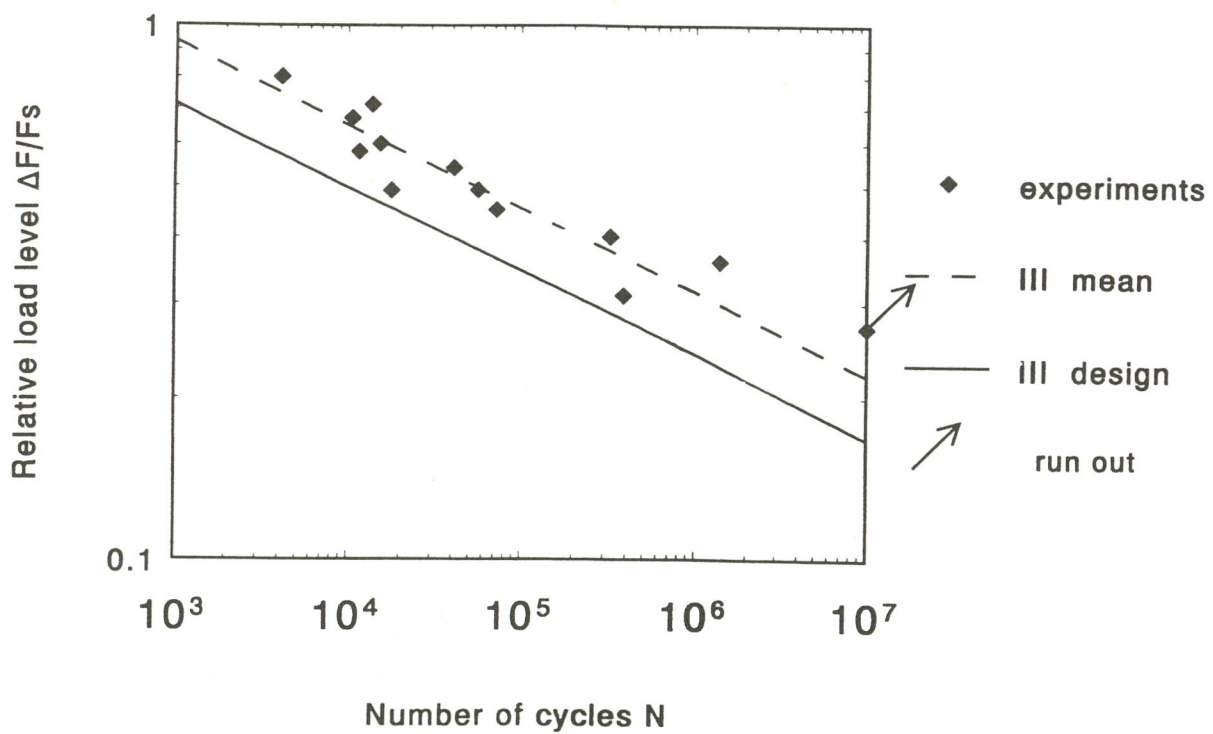
2- 11a Mean S-N curves group 11 (analyses I, II, III and IV/V)



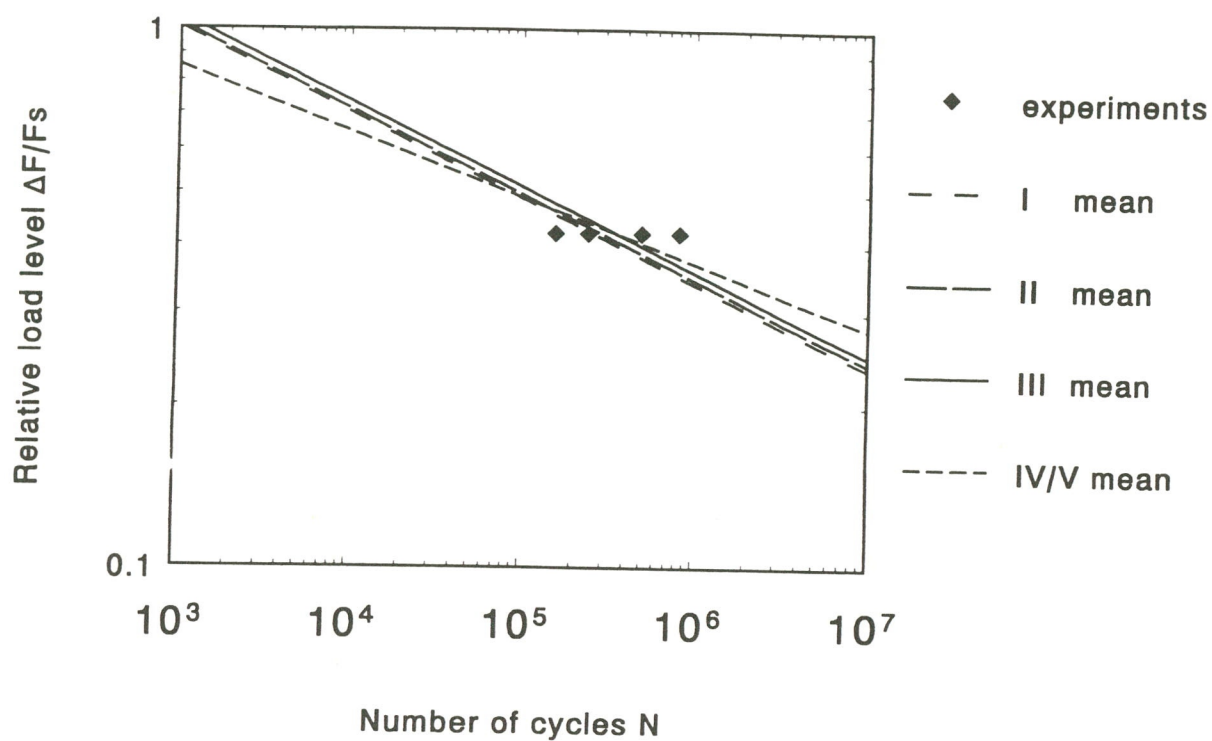
2- 11b Recommended mean and design S-N curve group 11 (analysis III)



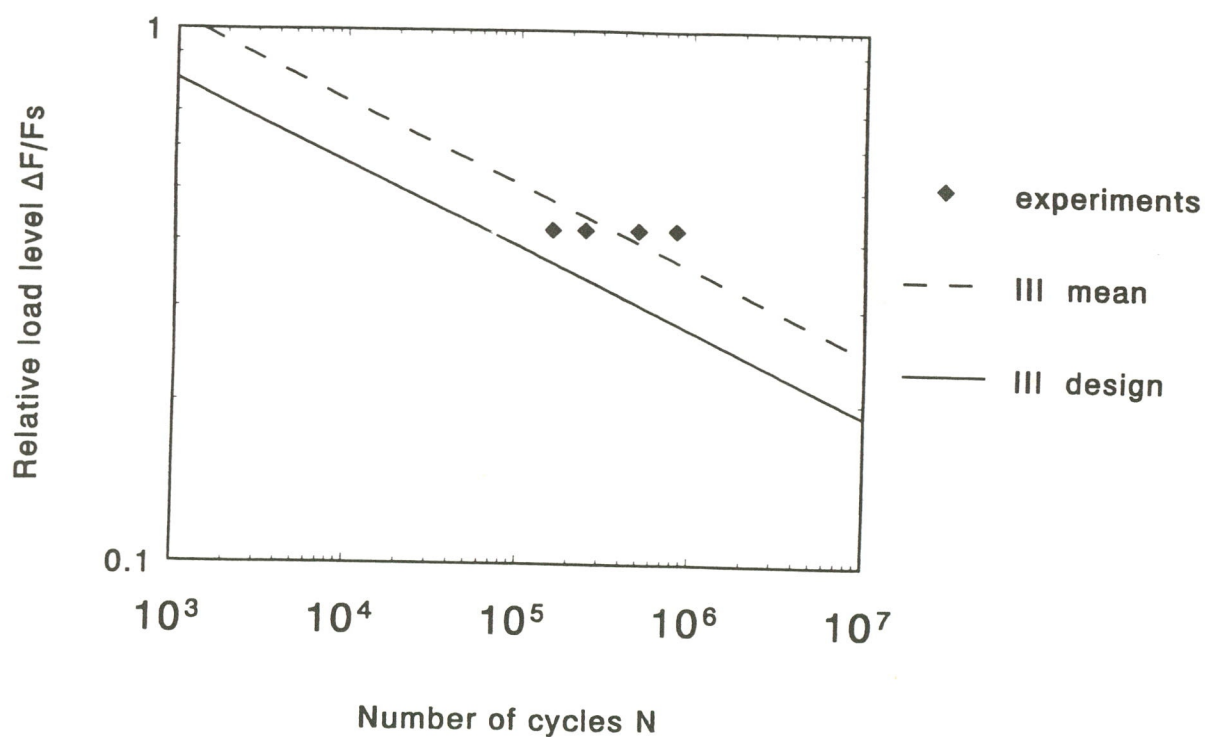
2- 12a Mean S-N curves group 12 (analyses I, II, III and IV/V)



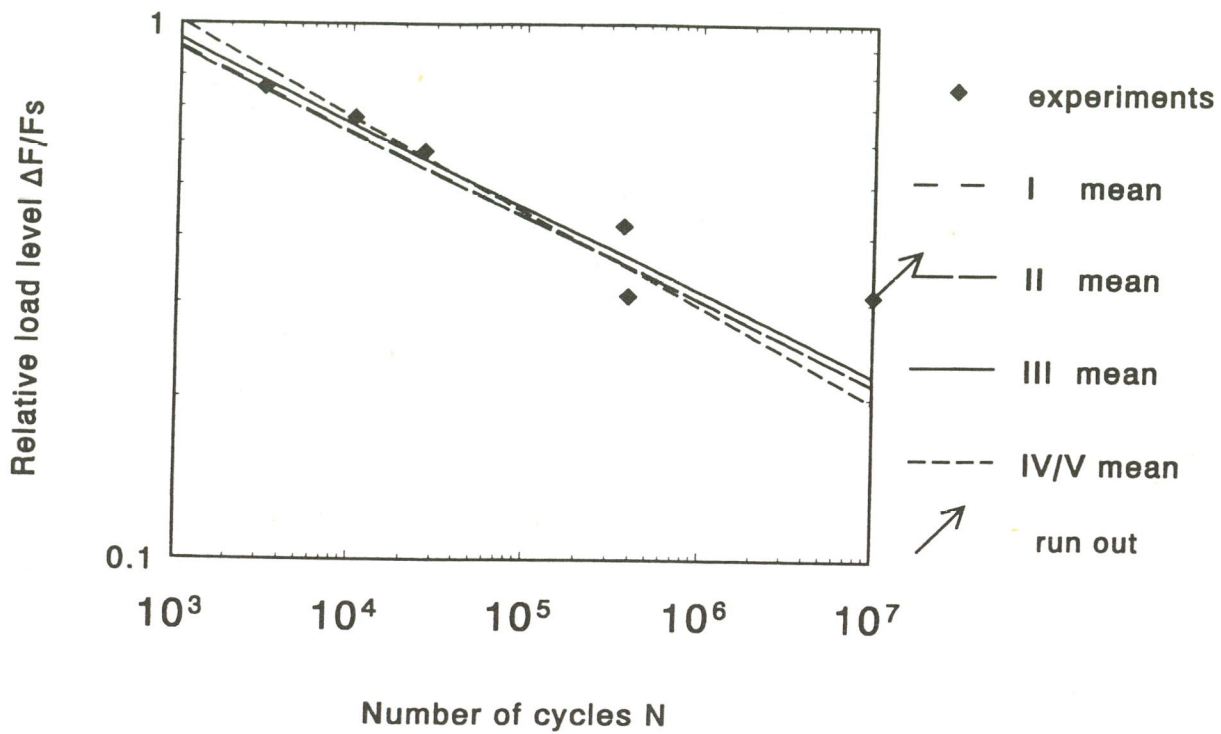
2- 12b Recommended mean and design S-N curve group 12 (analysis III)



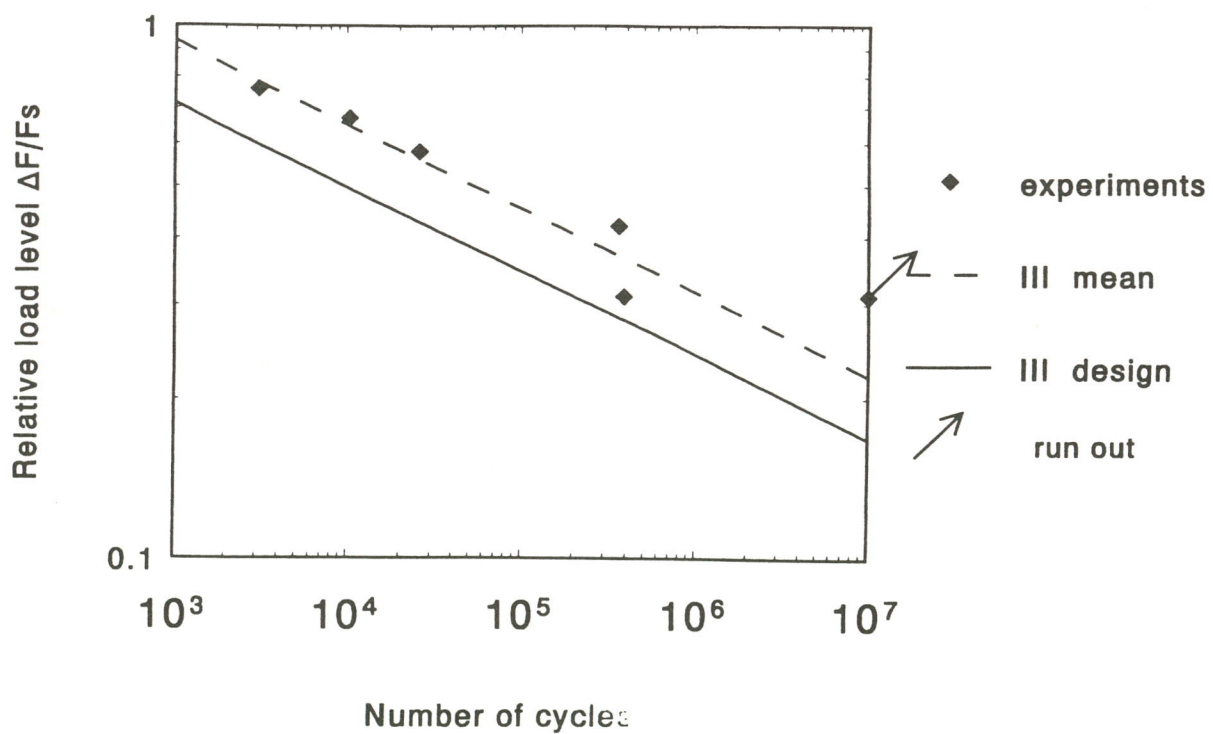
2- 13a Mean S-N curves group 13 (analyses I, II, III and IV/V)



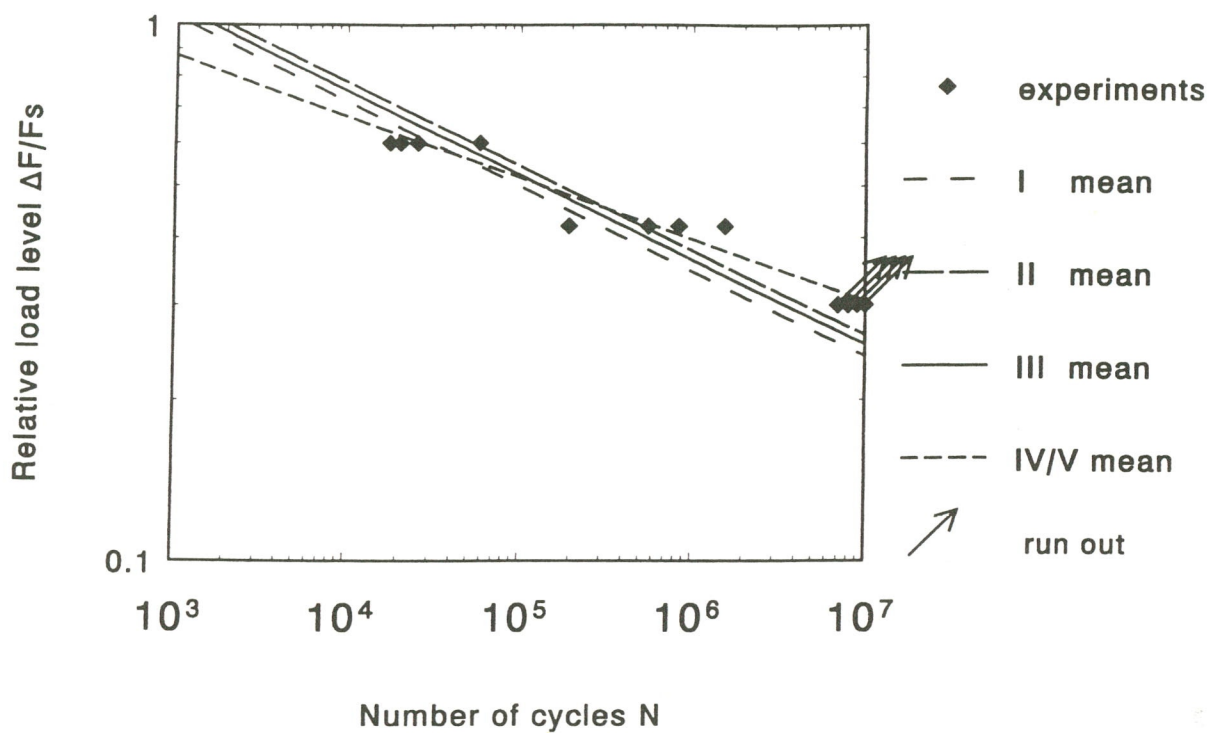
2- 13b Recommended mean and design S-N curve group 13 (analysis III)



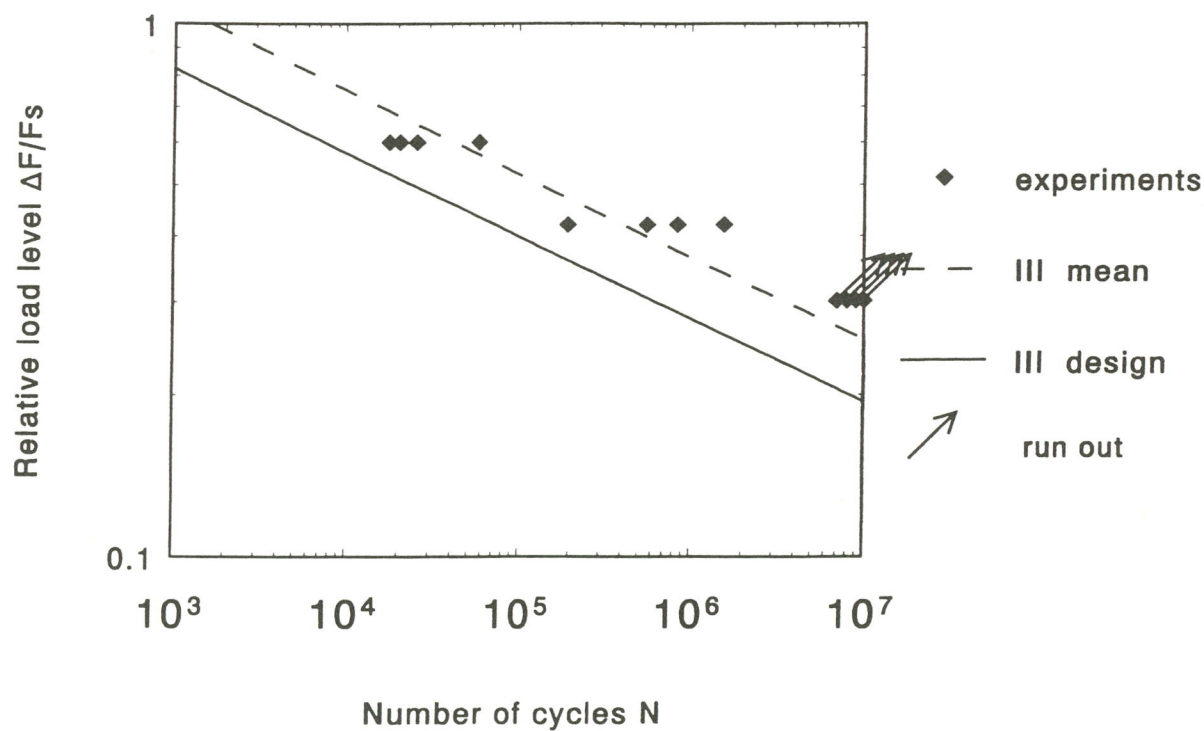
2- 14a Mean S-N curves group 14 (analyses I, II, III and IV/V)



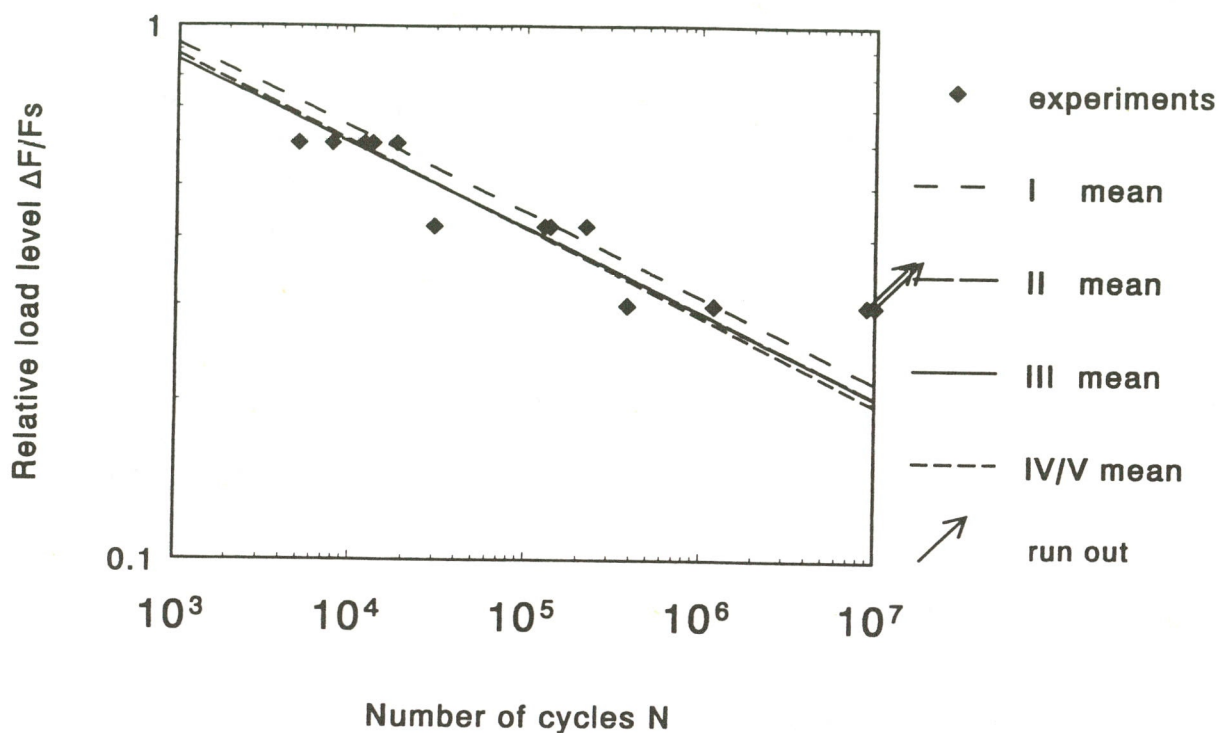
2- 14b Recommended mean and design S-N curve group 14 (analysis III)



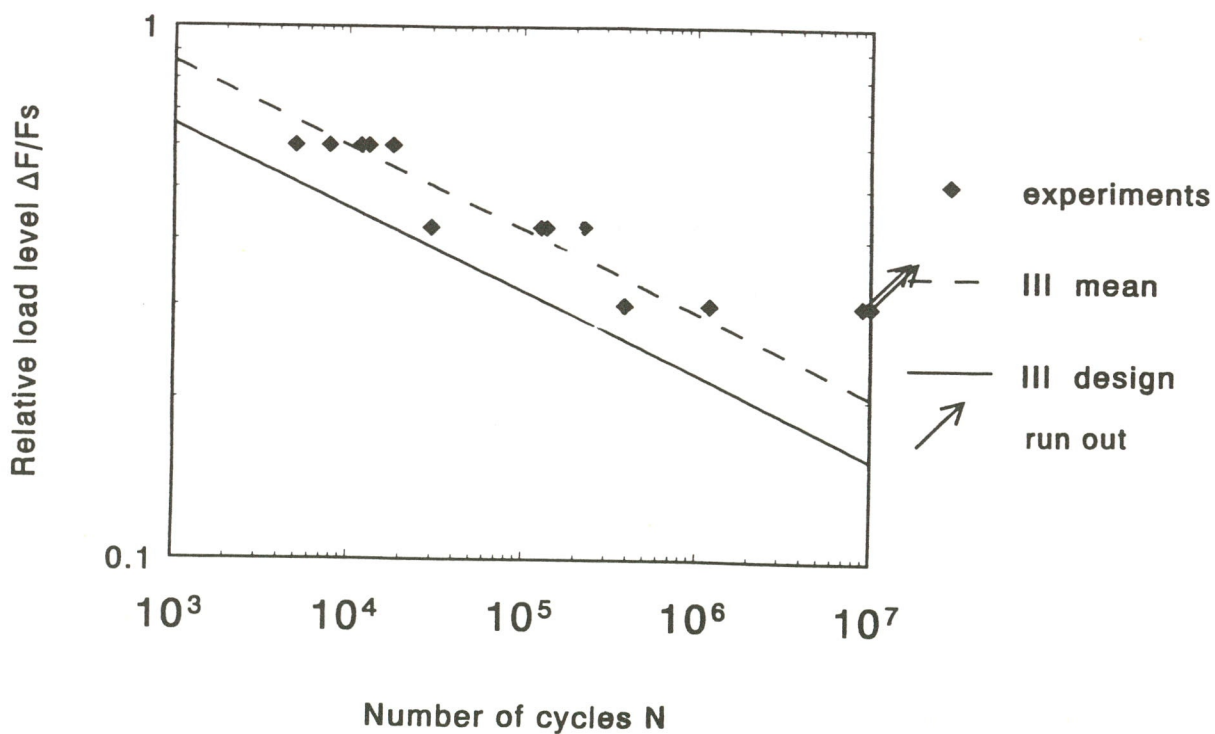
2- 15a Mean S-N curves group 15 (analyses I, II, III and IV/V)



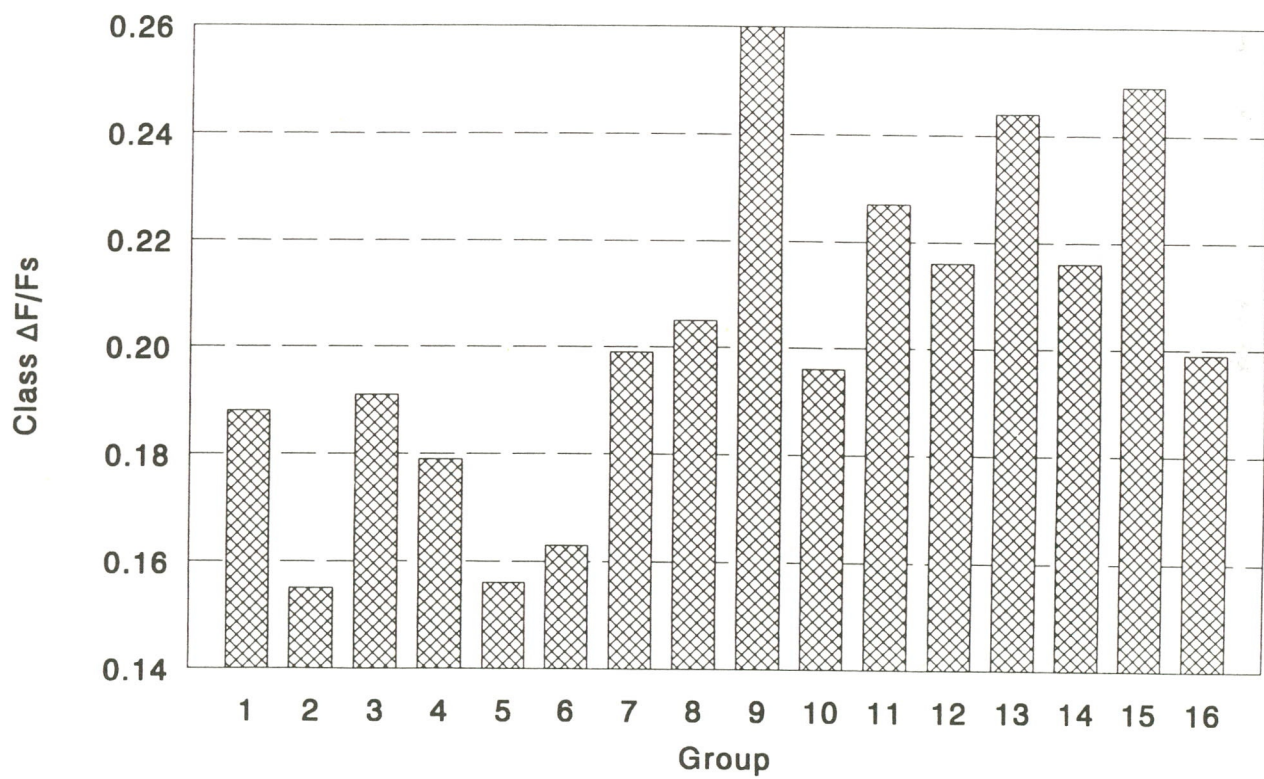
2- 15b Recommended mean and design S-N curve group 15 (analysis III)



2- 16a Mean S-N curves group 16 (analyses I, II, III and IV/V)



2- 16b Recommended mean and design S-N curve group 16 (analysis III)



APPENDICES

A Regression analyses with STATGRAPHICS 3.0

B Evaluation with MathCad

Appendix A

Regression analyses with STATGRAPHICS 3.0

Input file for STATGRAPHICS

N	S	A	B	C	D	L1	L2		
295214	0.37	10	10	10	10	20	10	6061/9323/D/air	(1)
16727	0.33	10	10	10	10	20	10		
330274	0.43	10	10	10	10	20	10		
98648	0.43	10	10	10	10	20	10		
358066	0.32	10	10	10	10	20	10		
28360	0.42	10	10	10	20	10	20	6061/9323/D/water	(2)
15010	0.42	10	10	10	20	10	20		
22290	0.42	10	10	10	20	10	20		
16340	0.42	10	10	10	20	10	20		
9500	0.60	10	10	20	10	20	20	6061/9323/CC/air	(3)
27610	0.60	10	10	20	10	20	20		
14260	0.60	10	10	20	10	20	20		
57290	0.60	10	10	20	10	20	20		
82520	0.42	10	10	20	10	20	20		
53610	0.42	10	10	20	10	20	20		
71200	0.42	10	10	20	10	20	20		
35710	0.42	10	10	20	10	20	20		
293600	0.30	10	10	20	10	20	20		
390200	0.30	10	10	20	10	20	20		
145100	0.30	10	10	20	10	20	20		
436000	0.30	10	10	20	10	20	20		
6290	0.60	10	10	20	20	10	10	6061/9323/CC/water	(4)
5580	0.60	10	10	20	20	10	10		
10280	0.60	10	10	20	20	10	10		
6300	0.60	10	10	20	20	10	10		
73630	0.42	10	10	20	20	10	10		
62130	0.42	10	10	20	20	10	10		
59700	0.42	10	10	20	20	10	10		
19500	0.42	10	10	20	20	10	10		
224040	0.30	10	10	20	20	10	10		
176480	0.30	10	10	20	20	10	10		
622750	0.30	10	10	20	20	10	10		
33080	0.42	10	20	10	10	20	20	6061/7823/D/air	(5)
51670	0.42	10	20	10	10	20	20		
21310	0.42	10	20	10	10	20	20		
4620	0.42	10	20	10	10	20	20		
29930	0.42	10	20	10	20	10	10	6061/7823/D/water	(6)
31720	0.42	10	20	10	20	10	10		
21410	0.42	10	20	10	20	10	10		
24050	0.42	10	20	10	20	10	10		

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N	S	A	B	C	D	L1	L2		
1219667	0.33	10	20	20	10	20	10	6061/7823/CC/air	(7)
483198	0.34	10	20	20	10	20	10		
190606	0.37	10	20	20	10	20	10		
150788	0.39	10	20	20	10	20	10		
81516	0.42	10	20	20	10	20	10		
32007	0.44	10	20	20	10	20	10		
17361	0.54	10	20	20	10	20	10		
7490	0.60	10	20	20	20	10	20	6061/7823/CC/water	(8)
4920	0.60	10	20	20	20	10	20		
8090	0.60	10	20	20	20	10	20		
1690	0.60	10	20	20	20	10	20		
43890	0.42	10	20	20	20	10	20		
27100	0.42	10	20	20	20	10	20		
53840	0.42	10	20	20	20	10	20		
69740	0.42	10	20	20	20	10	20	5754/9323/D/air	(9)
7011290	0.30	10	20	20	20	10	20		
7769970	0.30	10	20	20	20	10	20		
5674200	0.30	10	20	20	20	10	20		
4826330	0.30	10	20	20	20	10	20		
7870110	0.42	20	10	10	10	10	10		
9867250	0.42	20	10	10	10	10	10		
8986580	0.42	20	10	10	10	10	10	5754/9323/D/water	(10)
33230	0.42	20	10	10	20	20	20		
111810	0.42	20	10	10	20	20	20		
175060	0.42	20	10	10	20	20	20	5754/9323/CC/air	(11)
15200	0.60	20	10	20	10	10	20		
21070	0.60	20	10	20	10	10	20		
29940	0.60	20	10	20	10	10	20		
15570	0.60	20	10	20	10	10	20		
150770	0.42	20	10	20	10	10	20		
311280	0.42	20	10	20	10	10	20		
263240	0.42	20	10	20	10	10	20		
217590	0.42	20	10	20	10	10	20		
1691210	0.30	20	10	20	10	10	20		
1612230	0.30	20	10	20	10	10	20		
1355500	0.30	20	10	20	10	10	20		
3024060	0.30	20	10	20	10	10	20		
3802780	0.30	20	10	20	10	10	20		

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N	S	A	B	C	D	L1	L2	
10615	0.67	20	10	20	20	20	10	5754/9323/CC/water (12)
17805	0.49	20	10	20	20	20	10	
11693	0.58	20	10	20	20	20	10	
56414	0.49	20	10	20	20	20	10	
324738	0.40	20	10	20	20	20	10	
1402156	0.36	20	10	20	20	20	10	
15401	0.60	20	10	20	20	20	10	
40934	0.54	20	10	20	20	20	10	
13818	0.71	20	10	20	20	20	10	
72143	0.45	20	10	20	20	20	10	
4120	0.80	20	10	20	20	20	10	
387618	0.31	20	10	20	20	20	10	
492550	0.42	20	20	10	10	10	20	5754/7823/D/air (13)
816260	0.42	20	20	10	10	10	20	
156640	0.42	20	20	10	10	10	20	
241830	0.42	20	20	10	10	10	20	
3118	0.76	20	20	10	20	20	10	5754/7823/D/water (14)
10420	0.67	20	20	10	20	20	10	
26085	0.58	20	20	10	20	20	10	
361878	0.42	20	20	10	20	20	10	
387618	0.31	20	20	10	20	20	10	
58200	0.60	20	20	20	10	10	10	5754/7823/CC/air (15)
17860	0.60	20	20	20	10	10	10	
20460	0.60	20	20	20	10	10	10	
25670	0.60	20	20	20	10	10	10	
1565900	0.42	20	20	20	10	10	10	
561960	0.42	20	20	20	10	10	10	
841360	0.42	20	20	20	10	10	10	
195640	0.42	20	20	20	10	10	10	
7790	0.60	20	20	20	20	20	20	5754/7823/CC/water (16)
18110	0.60	20	20	20	20	20	20	
11890	0.60	20	20	20	20	20	20	
4970	0.60	20	20	20	20	20	20	
13190	0.60	20	20	20	20	20	20	
127400	0.42	20	20	20	20	20	20	
220470	0.42	20	20	20	20	20	20	
29870	0.42	20	20	20	20	20	20	
137020	0.42	20	20	20	20	20	20	
382000	0.30	20	20	20	20	20	20	
1187000	0.30	20	20	20	20	20	20	

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ANALYSIS I

Multiple Regression

Dep. var.: LOG10(N)

Ind. vars.: LOG10(A) & LOG10(B) & (LOG10(A))*(LOG10(B)) & LOG10(C) & LOG10(D)
LOG10(S)

Weights:

Constant: Yes Vertical bars: No Conf. level: 95

Model fitting results for: LOG10(N)

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-2.095088	2.628336	-0.7971	0.4271
LOG10(A)	4.841527	2.250209	2.1516	0.0336
LOG10(B)	3.069134	2.272308	1.3507	0.1795
(LOG10(A))*(LOG10(B))	-2.596884	1.959264	-1.3254	0.1877
LOG10(C)	0.205746	0.332311	0.6191	0.5371
LOG10(D)	-0.986296	0.298462	-3.3046	0.0013
LOG10(S)	-6.338365	0.420449	-15.0752	0.0000

R-SQ. (ADJ.) = 0.6979 SE= 0.478590 MAE= 0.329261 DurbWat= 1.134
 Previously: 0.6979 0.478590 0.329261 1.134
 118 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	63.2720	6	10.5453	46.0397	.0000
Error	25.4244	111	0.229049		
Total (Corr.)	88.6964	117			

R-squared = 0.713355

R-squared (Adj. for d.f.) = 0.69786

Std. error of est. = 0.47859

Durbin-Watson statistic = 1.13441

Residual Summary

Number of observations = 118 (0 missing values excluded)
Residual average = -6.56349E-15
Residual variance = 0.229049
Residual standard error = 0.47859

Coeff. of skewness = 0.877362 standardized value = 3.89085
Coeff. of kurtosis = 2.35127 standardized value = 5.2136

Durbin-Watson statistic = 1.13441

ANALYSIS II

Multiple Regression

 Dep. var.: LOG10(N)

Ind. vars.: LOG10(A) & LOG10(B) & (LOG10(A))*(LOG10(B)) & LOG10(C) & LOG10(D)
 LOG10(S)
 LOG10(L1) & LOG10(L2) & (LOG10(L1))*(LOG10(L2))

Weights:

Constant: Yes Vertical bars: No Conf. level: 95

Model fitting results for: LOG10(N)

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-0.052199	3.055715	-0.0171	0.9864
LOG10(A)	4.439873	2.465865	1.8005	0.0746
LOG10(B)	2.662405	2.469773	1.0780	0.2834
(LOG10(A))*(LOG10(B))	-2.216202	2.136966	-1.0371	0.3020
LOG10(C)	0.238565	0.324184	0.7359	0.4634
LOG10(D)	-1.049292	0.289869	-3.6199	0.0005
LOG10(S)	-6.379853	0.409913	-15.5639	0.0000
LOG10(L1)	-0.772048	2.484566	-0.3107	0.7566
LOG10(L2)	-0.640026	2.479598	-0.2581	0.7968
(LOG10(L1))*(LOG10(L2))	0.024522	2.137186	0.0115	0.9909

R-SQ. (ADJ.) = 0.7178 SE= 0.462490 MAE= 0.318745 DurbWat= 1.142
 Previously: 0.6979 0.478590 0.329261 1.134
 118 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	65.5954	9	7.28838	34.0742	.0000
Error	23.1009	108	0.213897		
Total (Corr.)	88.6964	117			

R-squared = 0.739551

R-squared (Adj. for d.f.) = 0.717846

Std. error of est. = 0.46249

Durbin-Watson statistic = 1.14187

Residual Summary

Number of observations = 118 (0 missing values excluded)
Residual average = -3.01454E-15
Residual variance = 0.213897
Residual standard error = 0.46249

Coeff. of skewness = 0.823417 standardized value = 3.65162
Coeff. of kurtosis = 1.7205 standardized value = 3.81497

Durbin-Watson statistic = 1.14187

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ANALYSIS III

Multiple Regression

Dep. var.: LOG10(N)

Ind. vars.: LOG10(A) & LOG10(B) & (LOG10(A))*(LOG10(B)) & LOG10(C) & LOG10(D)
 LOG10(S)
 (LOG10(A))*(LOG10(C)) & (LOG10(A))*(LOG10(D))
 (LOG10(B))*(LOG10(C)) & (LOG10(B))*(LOG10(D))
 (LOG10(C))*(LOG10(D))
 (LOG10(A))*(LOG10(B))*(LOG10(C)) & (LOG10(A))*(LOG10(B))*(LOG10(D))
 (LOG10(A))*(LOG10(C))*(LOG10(D)) & (LOG10(B))*(LOG10(C))*(LOG10(D))
 (LOG10(A))*(LOG10(B))*(LOG10(C))*(LOG10(D))

Weights:

Constant: Yes Vertical bars: No Conf. level: 95

Model fitting results for: LOG10(N)

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-360.276091	146.638471	-2.4569	0.0157
LOG10(A)	398.125594	128.063895	3.1088	0.0024
LOG10(B)	270.746839	126.450978	2.1411	0.0347
(LOG10(A))*(LOG10(B))	-300.736518	110.082784	-2.7319	0.0074
LOG10(C)	302.198053	119.753839	2.5235	0.0132
LOG10(D)	298.57996	126.450963	2.3612	0.0201
LOG10(S)	-6.363824	0.336207	-18.9283	0.0000
(LOG10(A))*(LOG10(C))	-327.058878	104.430418	-3.1318	0.0023
(LOG10(A))*(LOG10(D))	-325.467978	110.340509	-2.9497	0.0040
(LOG10(B))*(LOG10(C))	-231.915309	103.537063	-2.2399	0.0273
(LOG10(B))*(LOG10(D))	-232.017182	108.817252	-2.1322	0.0354
(LOG10(C))*(LOG10(D))	-253.167392	103.150411	-2.4544	0.0158
(LOG10(A))*(LOG10(B))*(LOG10(C))	253.093218	90.019721	2.8115	0.0059
(LOG10(A))*(LOG10(B))*(LOG10(D))	253.313765	94.648266	2.6764	0.0087
(LOG10(A))*(LOG10(C))*(LOG10(D))	271.21409	89.886812	3.0173	0.0032
(LOG10(B))*(LOG10(C))*(LOG10(D))	201.223886	88.957632	2.2620	0.0258
(LOG10(A))*(LOG10(B))* *(LOG10(C))*(LOG10(D))	-215.429202	77.294863	-2.7871	0.0064

R-SQ. (ADJ.) = 0.8174 SE= 0.372051 MAE= 0.257188 DurbWat= 1.647
 Previously: 0.7178 0.462490 0.318745 1.142
 118 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	74.7157	16	4.66973	33.7355	.0000
Error	13.9806	101	0.138422		
Total (Corr.)	88.6964	117			

R-squared = 0.842376

Std. error of est. = 0.372051

R-squared (Adj. for d.f.) = 0.817406

Durbin-Watson statistic = 1.64673

Residual Summary

Number of observations = 118 (0 missing values excluded)

Residual average = -1.36916E-12

Residual variance = 0.138422

Residual standard error = 0.372051

Coeff. of skewness = -0.0767926 standardized value = -0.340553

Coeff. of kurtosis = 1.49105 standardized value = 3.30619

Durbin-Watson statistic = 1.64673

ANALYSIS IV

Multiple Regression

 Dep. var.: LOG10(N)

Ind. vars.: LOG10(A) & LOG10(B) & (LOG10(A))*(LOG10(B)) & LOG10(C) & LOG10(D)
 LOG10(S)
 (LOG10(A))*(LOG10(C)) & (LOG10(A))*(LOG10(D))
 (LOG10(B))*(LOG10(C)) & (LOG10(B))*(LOG10(D))
 (LOG10(C))*(LOG10(D))
 (LOG10(A))*(LOG10(B))*(LOG10(C)) & (LOG10(A))*(LOG10(B))*(LOG10(D))
 (LOG10(A))*(LOG10(C))*(LOG10(D)) & (LOG10(B))*(LOG10(C))*(LOG10(D))
 (LOG10(A))*(LOG10(B))*(LOG10(C))*(LOG10(D))
 (LOG10(S))*(LOG10(A)) & (LOG10(S))*(LOG10(B))
 (LOG10(S))*(LOG10(C)) & (LOG10(S))*(LOG10(D))
 (LOG10(S))*(LOG10(A))*(LOG10(B)) & (LOG10(S))*(LOG10(A))*(LOG10(C))
 (LOG10(S))*(LOG10(A))*(LOG10(D)) & (LOG10(S))*(LOG10(B))*(LOG10(D))
 (LOG10(S))*(LOG10(A))*(LOG10(B))*(LOG10(D))

Weights:

Constant: Yes Vertical bars: No Conf. level: 95

Model fitting results for: LOG10(N)

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-179.444972	146.54666	-1.2245	0.2239
LOG10(A)	268.017243	126.643072	2.1163	0.0370
LOG10(B)	185.750461	123.442	1.5048	0.1358
(LOG10(A))*(LOG10(B))	-245.267737	108.083125	-2.2693	0.0256
LOG10(C)	177.230005	107.600519	1.6471	0.1029
LOG10(D)	206.564141	120.648411	1.7121	0.0902
LOG10(S)	120.955895	158.487589	0.7632	0.4473
(LOG10(A))*(LOG10(C))	-234.567365	92.239526	-2.5430	0.0127
(LOG10(A))*(LOG10(D))	-259.568149	105.481434	-2.4608	0.0157
(LOG10(B))*(LOG10(C))	-167.119516	88.566575	-1.8869	0.0623
(LOG10(B))*(LOG10(D))	-182.756117	104.695012	-1.7456	0.0842
(LOG10(C))*(LOG10(D))	-178.019736	87.816735	-2.0272	0.0455
(LOG10(A))*(LOG10(B))*(LOG10(C))	206.839843	76.874532	2.6906	0.0085
(LOG10(A))*(LOG10(B))*(LOG10(D))	221.784626	91.743677	2.4174	0.0176
(LOG10(A))*(LOG10(C))*(LOG10(D))	214.923523	76.276784	2.8177	0.0059
(LOG10(B))*(LOG10(C))*(LOG10(D))	149.071597	75.487458	1.9748	0.0513
(LOG10(A))*(LOG10(B))*(LOG10(C))* *(LOG10(D))	-177.296203	65.622987	-2.7017	0.0082

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(LOG10(S))*(LOG10(A))	-80.894883	133.855498	-0.6043	0.5471
(LOG10(S))*(LOG10(B))	26.656074	146.125142	0.1824	0.8557
(LOG10(S))*(LOG10(C))	-81.462005	38.659061	-2.1072	0.0378
(LOG10(S))*(LOG10(D))	35.501237	129.44263	0.2743	0.7845
(LOG10(S))*(LOG10(A))*(LOG10(B))	-38.793197	123.902886	-0.3131	0.7549
(LOG10(S))*(LOG10(A))*(LOG10(C))	61.323429	30.939584	1.9820	0.0505
(LOG10(S))*(LOG10(A))*(LOG10(D))	-37.747798	110.188109	-0.3426	0.7327
(LOG10(S))*(LOG10(B))*(LOG10(D))	-70.927524	119.232514	-0.5949	0.5534
(LOG10(S))*(LOG10(A))*(LOG10(B))* *(LOG10(D))	67.699509	101.362556	0.6679	0.5059

R-SQ. (ADJ.) = 0.8843 SE= 0.296140 MAE= 0.207599 DurbWat= 2.072
Previously: 0.8174 0.372051 0.257188 1.647
118 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	80.6281	25	3.22512	36.7750	.0000
Error	8.06830	92	0.0876989		
Total (Corr.)	88.6964	117			

R-squared = 0.909035 Stnd. error of est. = 0.29614
R-squared (Adj. for d.f.) = 0.884316 Durbin-Watson statistic = 2.07208

Residual Summary

Number of observations = 118 (0 missing values excluded)
Residual average = -7.66581E-13
Residual variance = 0.0876989
Residual standard error = 0.29614

Coeff. of skewness = -0.348657 standardized value = -1.54619
Coeff. of kurtosis = 0.217818 standardized value = 0.482981

Durbin-Watson statistic = 2.07208

ANALYSIS V

Multiple Regression

 Dep. var.: LOG10(N)

Ind. vars.: LOG10(A) & LOG10(B) & (LOG10(A))*(LOG10(B)) & LOG10(C) & LOG10(D)
 LOG10(S) & LOG10(L1) & LOG10(L2) & (LOG10(L1))*(LOG10(L2))
 (LOG10(A))*(LOG10(C))
 (LOG10(B))*(LOG10(C)) & (LOG10(B))*(LOG10(D))
 (LOG10(C))*(LOG10(D))
 (LOG10(A))*(LOG10(B))*(LOG10(D))
 (LOG10(A))*(LOG10(C))*(LOG10(D))
 (LOG10(A))*(LOG10(B))*(LOG10(C))*(LOG10(D))
 (LOG10(S))*(LOG10(A)) & (LOG10(S))*(LOG10(B))
 (LOG10(S))*(LOG10(C)) & (LOG10(S))*(LOG10(D))
 (LOG10(S))*(LOG10(A))*(LOG10(B)) & (LOG10(S))*(LOG10(A))*(LOG10(C))
 (LOG10(S))*(LOG10(A))*(LOG10(D)) & (LOG10(S))*(LOG10(B))*(LOG10(D))
 (LOG10(S))*(LOG10(A))*(LOG10(B))*(LOG10(D))

Weights:

Constant: Yes Vertical bars: No Conf. level: 95

Model fitting results for: LOG10(N)

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	788.439254	259.366308	3.0399	0.0031
LOG10(A)	-304.410553	99.621338	-3.0557	0.0029
LOG10(B)	-285.364088	105.625463	-2.7017	0.0082
(LOG10(A))*(LOG10(B))	-7.295395	46.926217	-0.1555	0.8768
LOG10(C)	-293.884543	100.11227	-2.9355	0.0042
LOG10(D)	-289.396708	101.114818	-2.8621	0.0052
LOG10(S)	120.955895	158.487589	0.7632	0.4473
LOG10(L1)	-74.887306	28.4933	-2.6282	0.0101
LOG10(L2)	-32.441225	11.63344	-2.7886	0.0064
(LOG10(L1))*(LOG10(L2))	31.132498	11.57077	2.6906	0.0085
(LOG10(A))*(LOG10(C))	3.404977	18.605402	0.1830	0.8552
(LOG10(B))*(LOG10(C))	242.361933	86.814894	2.7917	0.0064
(LOG10(B))*(LOG10(D))	-11.247009	45.614867	-0.2466	0.8058
(LOG10(C))*(LOG10(D))	-6.510627	11.361995	-0.5730	0.5680
(LOG10(A))*(LOG10(B))*(LOG10(D))	221.784626	91.743677	2.4174	0.0176
(LOG10(A))*(LOG10(C))*(LOG10(D))	214.923523	76.276784	2.8177	0.0059
(LOG10(A))*(LOG10(B))*(LOG10(C))* *(LOG10(D))	-177.296203	65.622987	-2.7017	0.0082

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(LOG10(S))*(LOG10(A))	-80.894883	133.855498	-0.6043	0.5471
(LOG10(S))*(LOG10(B))	26.656074	146.125142	0.1824	0.8557
(LOG10(S))*(LOG10(C))	-81.462005	38.659061	-2.1072	0.0378
(LOG10(S))*(LOG10(D))	35.501237	129.44263	0.2743	0.7845
(LOG10(S))*(LOG10(A))*(LOG10(B))	-38.793197	123.902886	-0.3131	0.7549
(LOG10(S))*(LOG10(A))*(LOG10(C))	61.323429	30.939584	1.9820	0.0505
(LOG10(S))*(LOG10(A))*(LOG10(D))	-37.747798	110.188109	-0.3426	0.7327
(LOG10(S))*(LOG10(B))*(LOG10(D))	-70.927524	119.232514	-0.5949	0.5534
(LOG10(S))*(LOG10(A))*(LOG10(B))* *(LOG10(D))	67.699509	101.362556	0.6679	0.5059

R-SQ. (ADJ.) = 0.8843 SE= 0.296140 MAE= 0.207599 DurbWat= 2.072
Previously: 0.8843 0.296140 0.207599 2.072
118 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

Analysis of Variance for the Full Regression

Source	Sum of Squares	DF	Mean Square	F-Ratio	P-value
Model	80.6281	25	3.22512	36.7750	.0000
Error	8.06830	92	0.0876989		
Total (Corr.)	88.6964	117			

R-squared = 0.909035 Stnd. error of est. = 0.29614
R-squared (Adj. for d.f.) = 0.884316 Durbin-Watson statistic = 2.07208

Residual Summary

Number of observations = 118 (0 missing values excluded)
Residual average = 2.18014E-12
Residual variance = 0.0876989
Residual standard error = 0.29614

Coeff. of skewness = -0.348657 standardized value = -1.54619
Coeff. of kurtosis = 0.217818 standardized value = 0.482981

Durbin-Watson statistic = 2.07208

Appendix B

Evaluation with MathCad

Input file "test" for experimental results
(number of cycles and load level)

295214	0.37
16727	0.33
330274	0.43
98648	0.43
358066	0.32
28360	0.42
15010	0.42
22290	0.42
16340	0.42
9500	0.60
27610	0.60
14260	0.60
57290	0.60
82520	0.42
53610	0.42
71200	0.42
35710	0.42
293600	0.30
390200	0.30
145100	0.30
436000	0.30
6290	0.60
5580	0.60
10280	0.60
6300	0.60
73630	0.42
62130	0.42
59700	0.42
19500	0.42
224040	0.30
176480	0.30
622750	0.30
33080	0.42
51670	0.42
21310	0.42
4620	0.42
29930	0.42
31720	0.42
21410	0.42
24050	0.42
1219667	0.33
483198	0.34
190606	0.37
150788	0.39
81516	0.42
32007	0.44
17361	0.54

7490	0.60
4920	0.60
8090	0.60
1690	0.60
43890	0.42
27100	0.42
53840	0.42
69740	0.42
7011290	0.30
7769970	0.30
5674200	0.30
4826330	0.30
7870110	0.42
9867250	0.42
8986580	0.42
33230	0.42
111810	0.42
175060	0.42
15200	0.60
21070	0.60
29940	0.60
15570	0.60
150770	0.42
311280	0.42
263240	0.42
217590	0.42
1691210	0.30
1612230	0.30
1355500	0.30
3024060	0.30
3802780	0.30
10615	0.67
17805	0.49
11693	0.58
56414	0.49
324738	0.40
1402156	0.36
15401	0.60
40934	0.54
13818	0.71
72143	0.45
4120	0.80
387618	0.31
492550	0.42
816260	0.42
156640	0.42
241830	0.42
3118	0.76
10420	0.67
26085	0.58

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361878	0.42
387618	0.31
58200	0.60
17860	0.60
20460	0.60
25670	0.60
1565900	0.42
561960	0.42
841360	0.42
195640	0.42
7790	0.60
18110	0.60
11890	0.60
4970	0.60
13190	0.60
127400	0.42
220470	0.42
29870	0.42
137020	0.42
382000	0.30
1187000	0.30

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I-1

Multi regression analysis for aluminium bonded joints

ANALYSIS I

ORIGIN := 1

index i := 1..16 j := 1..3

DUMMY PARAMETERS

group	alloy	adhesive	pretreatm	environm	laboratory	
$g :=$	$A :=$	$B :=$	$C :=$	$D :=$	$L1 :=$	$L2 :=$
1	10	10	10	10	20	10
2	10	10	10	20	10	20
3	10	10	20	10	20	20
4	10	10	20	20	10	10
5	10	20	10	10	20	20
6	10	20	10	20	10	10
7	10	20	20	10	20	10
8	10	20	20	20	10	20
9	20	10	10	10	10	10
10	20	10	10	20	20	20
11	20	10	20	10	10	20
12	20	10	20	20	20	10
13	20	20	10	10	10	20
14	20	20	10	20	20	10
15	20	20	20	10	10	10
16	20	20	20	20	20	20

LOAD LEVEL $S_1 := 0.60$ $S_2 := 0.42$ $S_3 := 0.30$

EXPERIMENTAL RESULTS

E := READPRN(test)

LOG values of parameters

 $a_i := \log(A_i)$ $b_i := \log(B_i)$ $c_i := \log(C_i)$ $d_i := \log(D_i)$ $l1_i := \log(L1_i)$ $l2_i := \log(L2_i)$ $s_j := \log(S_j)$

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I-2

REGRESSION COEFFICIENTS

$$m0 := -2.095088$$

$$ma := 4.841527$$

$$mb := 3.069134$$

$$mab := -2.596884$$

$$mc := 0.205746$$

$$md := -0.986296$$

$$ms := -6.338365$$

$$stdv := 0.47859$$

MEAN REGRESSION LINES

$$\log N1_{i,j} := m0 + ma \cdot a_i + mb \cdot b_i + mab \cdot a_i \cdot b_i + mc \cdot c_i + md \cdot d_i + ms \cdot s_j$$

$$N1_{i,j} := 10^{\log N1_{i,j}}$$

DESIGN REGRESSION LINES (Mean minus two standard deviations)

$$\log N2_{i,j} := \log N1_{i,j} - 2 \cdot stdv$$

$$N2_{i,j} := 10^{\log N2_{i,j}}$$

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I-3

NUMBER OF CYCLES FOR EACH SERIE AND LOAD LEVEL

group i	Mean	level			Design	level	
	0.60	0.42	0.30	0.60	0.42	0.30	
	$N1_{i,1}$	$N1_{i,2}$	$N1_{i,3}$	$N2_{i,1}$	$N2_{i,2}$	$N2_{i,3}$	
1	6987	67007	565373	771	7395	62396	
2	3527	33823	285385	389	3733	31496	
3	8058	77278	652035	889	8529	71960	
4	4068	39008	329129	449	4305	36323	
5	9693	92957	784326	1070	10259	86560	
6	4893	46922	395906	540	5178	43693	
7	11179	107206	904550	1234	11831	99828	
8	5643	54115	456591	623	5972	50390	
9	33113	317561	2679416	3654	35047	295706	
10	16715	160296	1352495	1845	17691	149264	
11	38189	366238	3090124	4215	40419	341033	
12	19277	184867	1559808	2127	20402	172144	
13	26720	256249	2162093	2949	28280	238613	
14	13488	129347	1091364	1489	14275	120445	
15	30816	295527	2493505	3401	32615	275188	
16	15555	149174	1258651	1717	16463	138907	

slope and level of S-N curve

Mean

Design

Slope

$$m1_i := \frac{\log\left(\frac{N1_{i,3}}{N1_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

$$m2_i := \frac{\log\left(\frac{N2_{i,3}}{N2_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

Constant

$$C1_i := N1_{i,1} \cdot (S_1)^{m1_i}$$

$$C2_i := N2_{i,1} \cdot (S_1)^{m2_i}$$

Level at 2 million cycles

$$L1_{2m_i} := \left[\frac{C1_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m1_i} \right)}$$

$$L2_{2m_i} := \left[\frac{C2_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m2_i} \right)}$$

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SLOPE, CONSTANT, NUMBER OF CYCLES AT MEAN LEVEL AND AT 2 MILLION CYCLES^{I-4}

Mean					Design			
i	m1 _i	C1 _i	N1 _{i,2}	L1_2m _i	m2 _i	C2 _i	N2 _{i,2}	L2_2m _i
1	6.338	274	67007	0.246	6.338	30	7395	0.174
2	6.338	138	33823	0.221	6.338	15	3733	0.156
3	6.338	316	77278	0.251	6.338	35	8529	0.178
4	6.338	160	39008	0.226	6.338	18	4305	0.159
5	6.338	380	92957	0.259	6.338	42	10259	0.183
6	6.338	192	46922	0.232	6.338	21	5178	0.164
7	6.338	439	107206	0.265	6.338	48	11831	0.187
8	6.338	221	54115	0.238	6.338	24	5972	0.168
9	6.338	1300	317561	0.314	6.338	143	35047	0.222
10	6.338	656	160296	0.282	6.338	72	17691	0.199
11	6.338	1499	366238	0.321	6.338	165	40419	0.227
12	6.338	757	184867	0.288	6.338	84	20402	0.204
13	6.338	1049	256249	0.304	6.338	116	28280	0.215
14	6.338	529	129347	0.273	6.338	58	14275	0.193
15	6.338	1210	295527	0.311	6.338	133	32615	0.219
16	6.338	611	149174	0.279	6.338	67	16463	0.197

index k := 1..8 p := 1..4

Influence factor air/water at mean level

$$T_k := 2 \cdot k - 1 \quad N_k := 2 \cdot k \quad f1_{aw_k} := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

Average

arithmetic

$$\frac{\sum_k f1_{aw_k}}{8} = 1.981$$

geometrical

$$\left(\prod_k f1_{aw_k} \right)^{\frac{1}{8}} = 1.981$$

T _k	N _k	f1 _{aw_k}
1	2	1.981
3	4	1.981
5	6	1.981
7	8	1.981
9	10	1.981
11	12	1.981
13	14	1.981
15	16	1.981

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Influence factor pretreatment at mean level

$$T_1 := 1 \quad T_2 := 2 \quad T_3 := 5 \quad T_4 := 6 \quad T_5 := 9 \quad T_6 := 10 \quad T_7 := 13 \quad T_8 := 14$$

$$N_1 := 3 \quad N_2 := 4 \quad N_3 := 7 \quad N_4 := 8 \quad N_5 := 11 \quad N_6 := 12 \quad N_7 := 15 \quad N_8 := 16$$

$$f1_DCC_k := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

$$\frac{\sum_k f1_DCC_k}{8} = 0.867$$

$$\left(\prod_k f1_DCC_k \right)^{\frac{1}{8}} = 0.867$$

T_k	N_k	$f1_DCC_k$
1	3	0.867
2	4	0.867
5	7	0.867
6	8	0.867
9	11	0.867
10	12	0.867
13	15	0.867
14	16	0.867

Relative influence factor specimen at mean level**Specimen type 1 (6061-T6 / 9323)**

$$f1_1_p := \frac{4 \cdot N1_{p,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_1_p}{4} = 0.365 \quad \left(\prod_p f1_1_p \right)^{\frac{1}{4}} = 0.365$$

Specimen type 2 (6061-T6 / 7823)

$$f1_2_p := \frac{4 \cdot N1_{p+4,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_2_p}{4} = 0.507 \quad \left(\prod_p f1_2_p \right)^{\frac{1}{4}} = 0.507$$

Specimen type 3 (5754-WH / 9323)

$$f1_3_p := \frac{4 \cdot N1_{p+8,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_3_p}{4} = 1.731 \quad \left(\prod_p f1_3_p \right)^{\frac{1}{4}} = 1.731$$

Specimen type 4 (5754-WH / 7823)

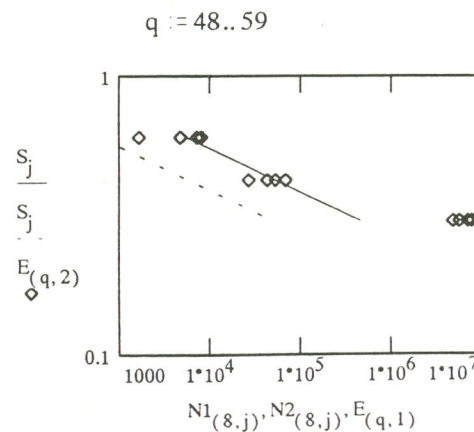
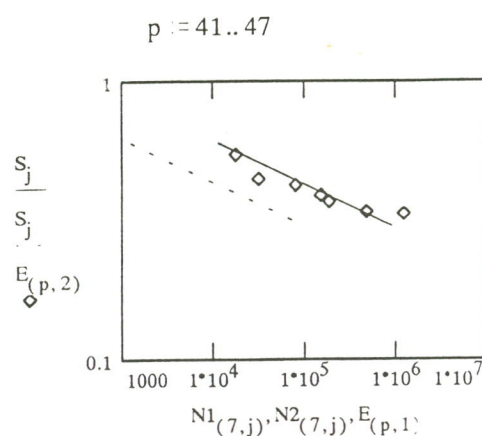
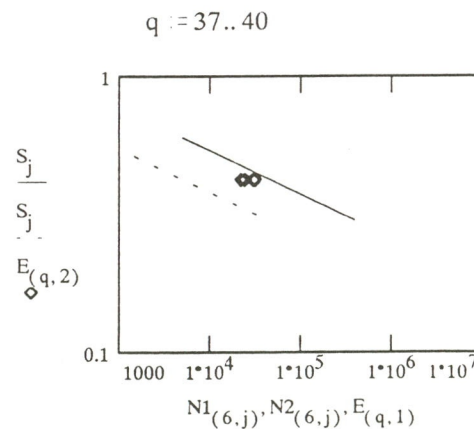
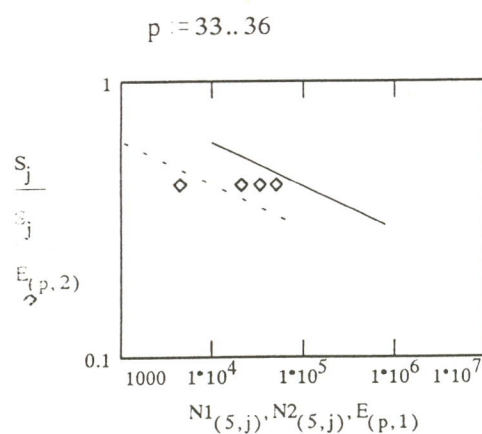
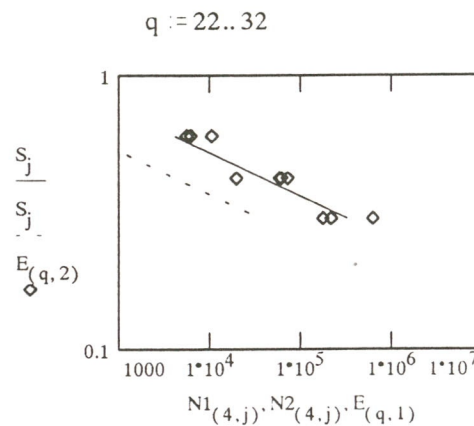
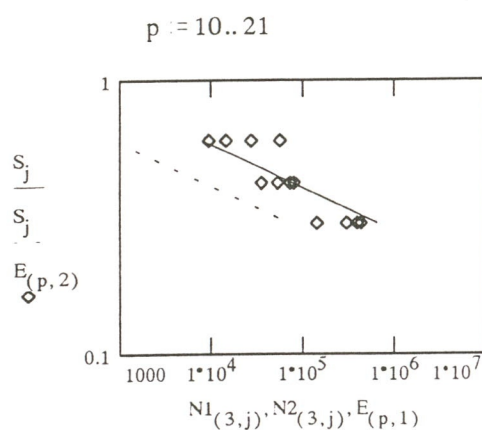
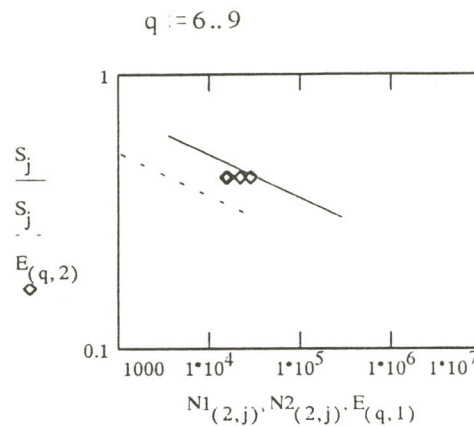
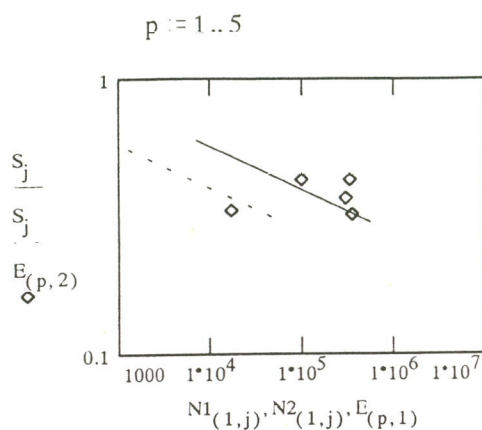
$$f1_4_p := \frac{4 \cdot N1_{p+12,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_4_p}{4} = 1.397 \quad \left(\prod_p f1_4_p \right)^{\frac{1}{4}} = 1.397$$

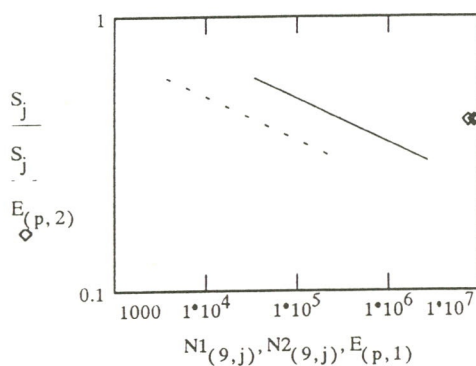
Overview

$f1_1_p$	$f1_2_p$	$f1_3_p$	$f1_4_p$
0.365	0.507	1.731	1.397
0.365	0.507	1.731	1.397
0.365	0.507	1.731	1.397
0.365	0.507	1.731	1.397

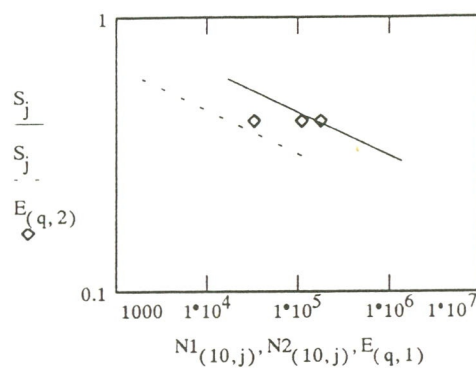
S-N curves and experimental results per group



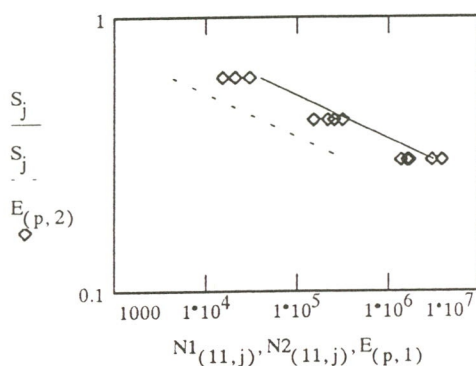
p := 60..62



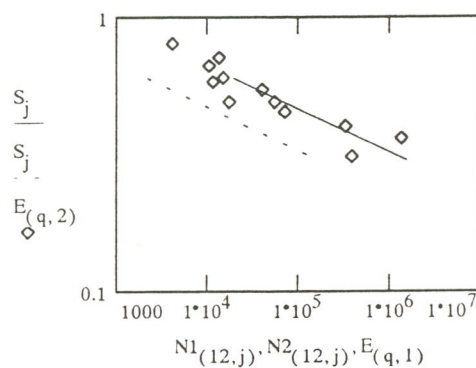
q := 63..65



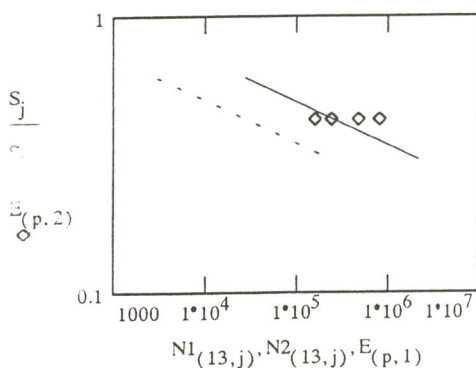
p := 66..78



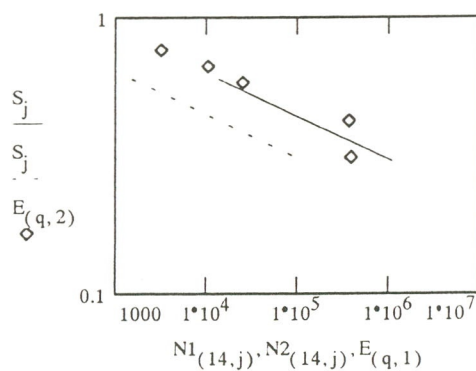
q := 79..90



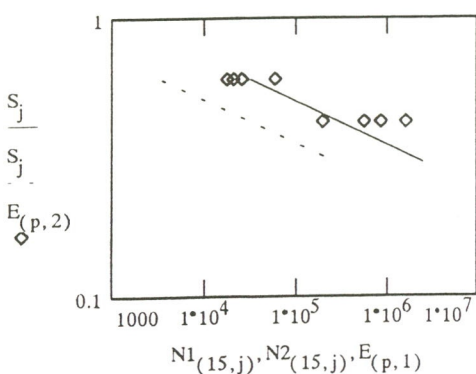
p := 91..94



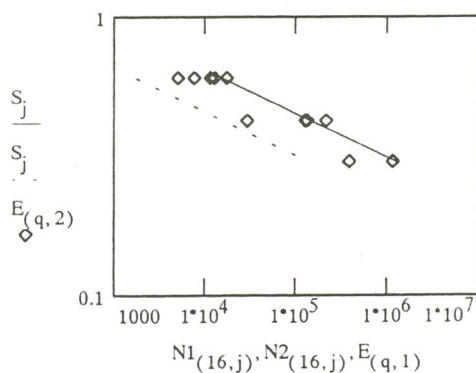
q := 95..99



p := 100..107



q := 108..118



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II-1

Multi regression analysis for aluminium bonded joints

ANALYSIS II

ORIGIN := 1

index i := 1..16 j := 1..3

DUMMY PARAMETERS

group	alloy	adhesive	pretreatm	environm	laboratory	
$g :=$	$A :=$	$B :=$	$C :=$	$D :=$	$L1 =$	$L2 :=$
1	10	10	10	10	20	10
2	10	10	10	20	10	20
3	10	10	20	10	20	20
4	10	10	20	20	10	10
5	10	20	10	10	20	20
6	10	20	10	20	10	10
7	10	20	20	10	20	10
8	10	20	20	20	10	20
9	20	10	10	10	10	10
10	20	10	10	20	20	20
11	20	10	20	10	10	20
12	20	10	20	20	20	10
13	20	20	10	10	10	20
14	20	20	10	20	20	10
15	20	20	20	10	10	10
16	20	20	20	20	20	20

LOAD LEVEL $S_1 := 0.60$ $S_2 := 0.42$ $S_3 := 0.30$

EXPERIMENTAL RESULTS

E := READPRN(test)

LOG values of parameters

 $a_i := \log(A_i)$ $b_i := \log(B_i)$ $c_i := \log(C_i)$ $d_i := \log(D_i)$ $l1_i := \log(L1_i)$ $l2_i := \log(L2_i)$ $s_j := \log(S_j)$

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II-2

REGRESSION COEFFICIENTS

$$m0 := -0.052199$$

$$ma := 4.439873 \quad mb := 2.662405 \quad mab := -2.216202$$

$$mc := 0.238565 \quad md := -1.049292$$

$$ms := -6.379853$$

$$m11 := -0.772048 \quad m12 := -0.640026 \quad m112 := 0.024522$$

$$std := 0.46249$$

MEAN REGRESSION LINES

$$\log N1_{-1,i,j} := m0 + ma \cdot a_i + mb \cdot b_i + mab \cdot a_i \cdot b_i + mc \cdot c_i + md \cdot d_i + ms \cdot s_j$$

$$\log N1_{-2,i,j} := m11 \cdot l1_i + m12 \cdot l2_i + m112 \cdot l1_i \cdot l2_i$$

$$\log N1_{i,j} := \log N1_{-1,i,j} + \log N1_{-2,i,j}$$

$$N1_{i,j} = 10^{\log N1_{i,j}}$$

DESIGN REGRESSION LINES (Mean minus two standard deviations)

$$\log N2_{i,j} := \log N1_{i,j} - 2 \cdot stdv$$

$$N2_{i,j} := 10^{\log N2_{i,j}}$$

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II-3

NUMBER OF CYCLES FOR EACH SERIE AND LOAD LEVEL

group i	Mean level			Design level		
	0.60 N1 _{i,1}	0.42 N1 _{i,2}	0.30 N1 _{i,3}	0.60 N2 _{i,1}	0.42 N2 _{i,2}	0.30 N2 _{i,3}
1	6698	65191	557776	796	7748	66295
2	3547	34519	295348	422	4103	35104
3	5184	50459	431730	616	5997	51314
4	6411	62396	533869	762	7416	63453
5	5987	58270	498560	712	6926	59257
6	7403	72055	616509	880	8564	73276
7	10766	104790	896593	1280	12455	106565
8	5701	55487	474755	678	6595	56427
9	52523	511215	4374004	6243	60761	519875
10	9917	96526	825886	1179	11473	98161
11	40447	393671	3368288	4807	46790	400340
12	17835	173589	1485246	2120	20632	176530
13	29414	286292	2449539	3496	34027	291142
14	12970	126240	1080124	1542	15004	128379
15	53169	517499	4427767	6319	61508	526265
16	10039	97713	836037	1193	11614	99368

slope and level of S-N curve

Mean

Design

Slope

$$m1_i = \frac{\log\left(\frac{N1_{i,3}}{N1_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

$$m2_i = \frac{\log\left(\frac{N2_{i,3}}{N2_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

Constant

$$C1_i = N1_{i,1} \cdot (S_1)^{m1_i}$$

$$C2_i = N2_{i,1} \cdot (S_1)^{m2_i}$$

Level at 2 million cycles

$$L1_{2m_i} = \left[\frac{C1_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m1_i} \right)}$$

$$L2_{2m_i} = \left[\frac{C2_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m2_i} \right)}$$

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II-4

SLOPE, CONSTANT, NUMBER OF CYCLES AT MEAN LEVEL AND AT 2 MILLION CYCLES

Mean					Design			
i	m1 _i	C1 _i	N1 _{i,2}	L1_2m _i	m2 _i	C2 _i	N2 _{i,2}	L2_2m _i
1	6.38	257	65191	0.246	6.38	31	7748	0.176
2	6.38	136	34519	0.222	6.38	16	4103	0.159
3	6.38	199	50459	0.236	6.38	24	5997	0.169
4	6.38	246	62396	0.244	6.38	29	7416	0.175
5	6.38	230	58270	0.241	6.38	27	6926	0.173
6	6.38	284	72055	0.249	6.38	34	8564	0.179
7	6.38	414	104790	0.265	6.38	49	12455	0.189
8	6.38	219	55487	0.239	6.38	26	6595	0.171
9	6.38	2018	511215	0.339	6.38	240	60761	0.243
10	6.38	381	96526	0.261	6.38	45	11473	0.187
11	6.38	1554	393671	0.326	6.38	185	46790	0.233
12	6.38	685	173589	0.286	6.38	81	20632	0.205
13	6.38	1130	286292	0.31	6.38	134	34027	0.222
14	6.38	498	126240	0.272	6.38	59	15004	0.195
15	6.38	2043	517499	0.34	6.38	243	61508	0.243
16	6.38	386	97713	0.262	6.38	46	11614	0.187

index k := 1..8 p := 1..4

Influence factor air/water at mean level

$$T_k := 2 \cdot k - 1 \quad N_k := 2 \cdot k \quad f1_{aw_k} := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

Average

arithmetic

$$\frac{\sum_k f1_{aw_k}}{8} = 2.565$$

geometrical

$$\left(\prod_k f1_{aw_k} \right)^{\frac{1}{8}} = 2.07$$

T _k	N _k	f1 _{aw_k}
1	2	1.889
3	4	0.809
5	6	0.809
7	8	1.889
9	10	5.296
11	12	2.268
13	14	2.268
15	16	5.296

Influence factor pretreatment at mean level

$$T_1 := 1 \quad T_2 := 2 \quad T_3 := 5 \quad T_4 := 6 \quad T_5 := 9 \quad T_6 := 10 \quad T_7 := 13 \quad T_8 := 14$$

$$N_1 := 3 \quad N_2 := 4 \quad N_3 := 7 \quad N_4 := 8 \quad N_5 := 11 \quad N_6 := 12 \quad N_7 := 15 \quad N_8 := 16$$

$$f1_DCC_k := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

$$\frac{\sum_k f1_DCC_k}{8} = 0.925$$

$$\left(\prod_k f1_DCC_k \right)^{\frac{1}{8}} = 0.848$$

T_k	N_k	$f1_DCC_k$
1	3	1.292
2	4	0.553
5	7	0.556
6	8	1.299
9	11	1.299
10	12	0.556
13	15	0.553
14	16	1.292

Relative influence factor specimen at mean level

Specimen type 1 (6061-T6 / 9323)

$$f1_1_p := \frac{4 \cdot N1_{p,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_1_p}{4} = 0.383 \quad \left(\prod_p f1_1_p \right)^{\frac{1}{4}} = 0.346$$

Specimen type 2 (6061-T6 / 7823)

$$f1_2_p := \frac{4 \cdot N1_{p+4,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_2_p}{4} = 0.523 \quad \left(\prod_p f1_2_p \right)^{\frac{1}{4}} = 0.472$$

Specimen type 3 (5754-WH / 9323)

$$f1_3_p := \frac{4 \cdot N1_{p+8,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_3_p}{4} = 1.663 \quad \left(\prod_p f1_3_p \right)^{\frac{1}{4}} = 1.618$$

Specimen type 4 (5754-WH / 7823)

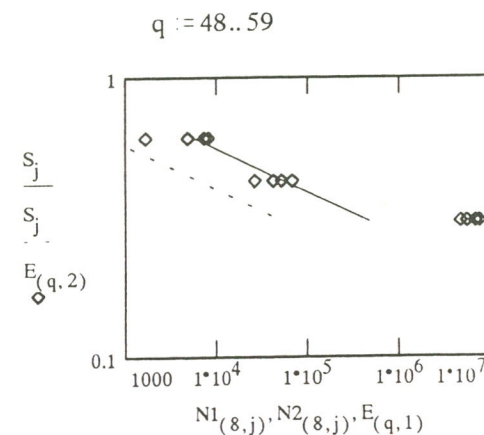
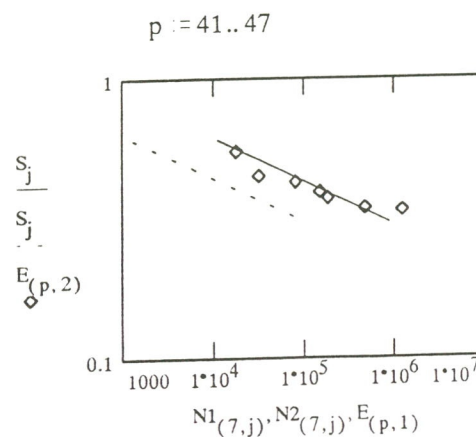
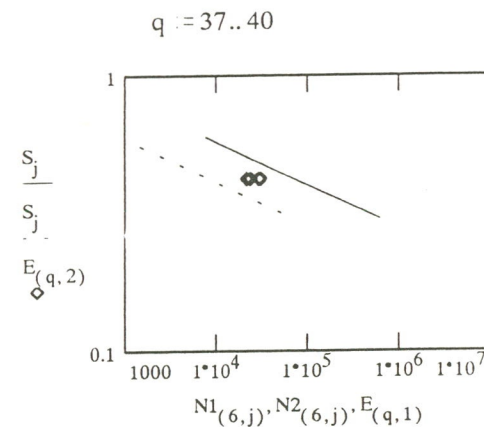
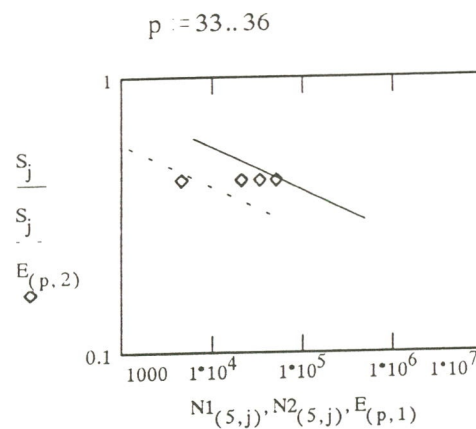
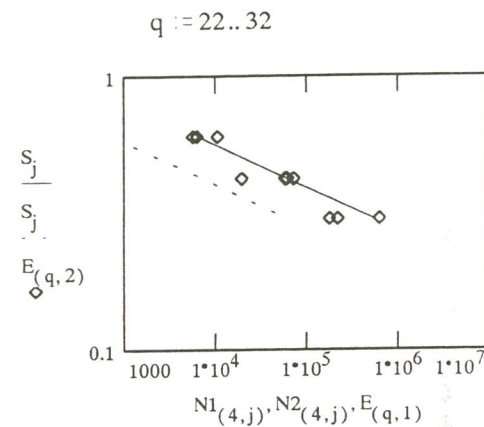
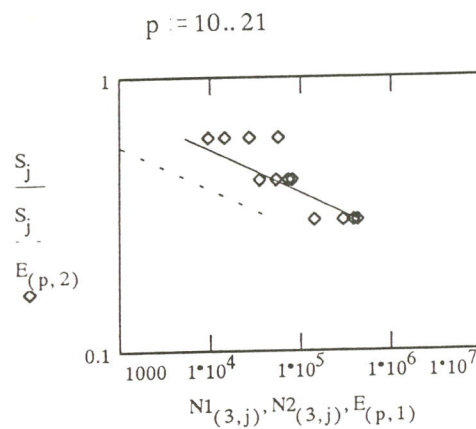
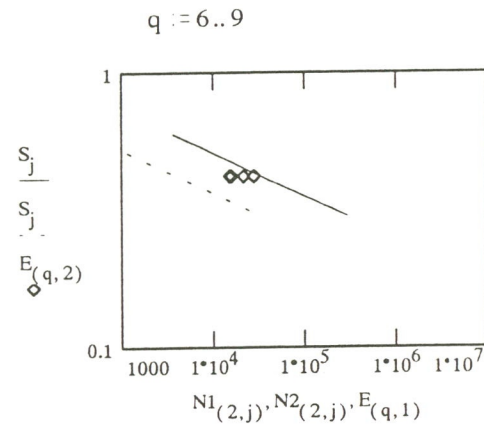
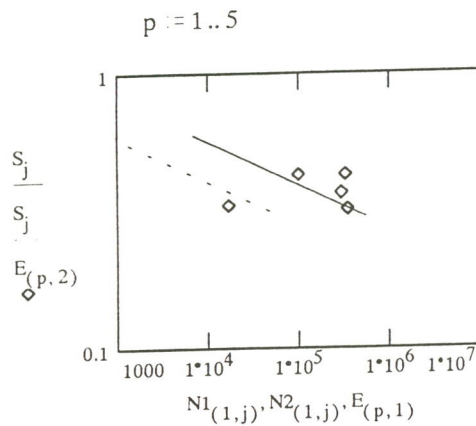
$$f1_4_p := \frac{4 \cdot N1_{p+12,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_4_p}{4} = 1.431 \quad \left(\prod_p f1_4_p \right)^{\frac{1}{4}} = 1.388$$

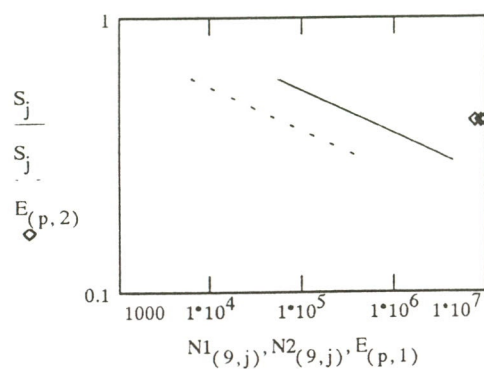
Overview

$f1_1_p$	$f1_2_p$	$f1_3_p$	$f1_4_p$
0.283	0.253	2.22	1.243
0.419	0.875	1.172	1.533
0.189	0.393	1.477	1.941
0.641	0.57	1.784	1.004

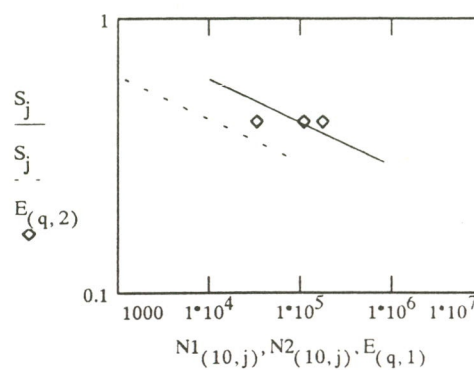
S-N curves and experimental results per group



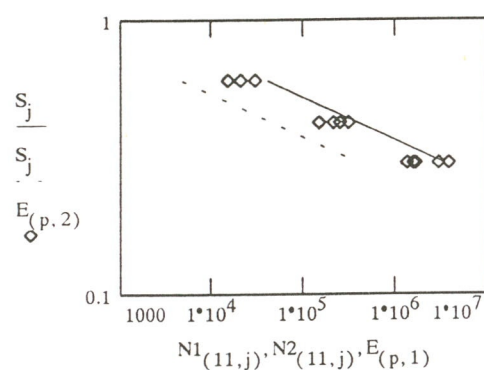
p = 60..62



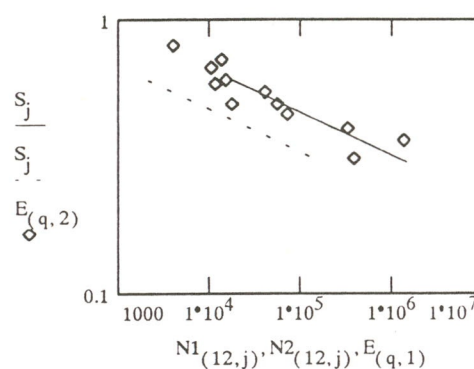
q = 63..65



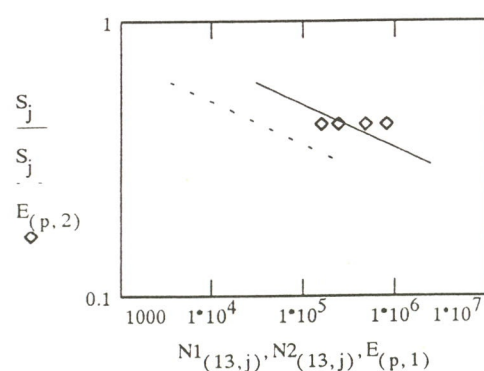
p = 66..78



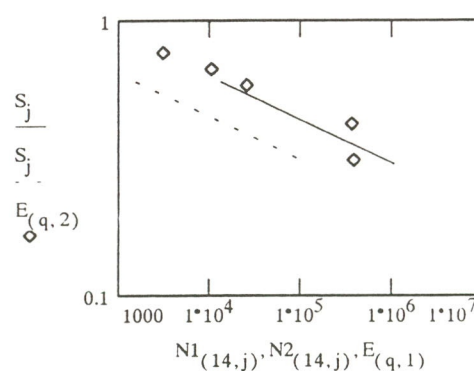
q = 79..90



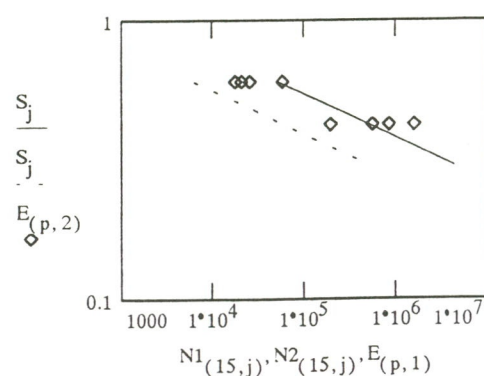
p = 91..94



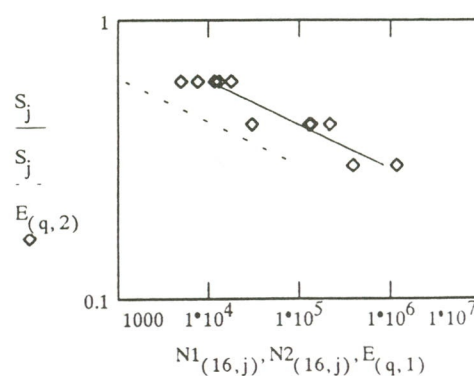
q = 95..99



p = 100..107



q = 108..118



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III-1

Multi regression analysis for aluminium bonded joints

ANALYSIS III

ORIGIN := 1

index i := 1..16 j := 1..3

DUMMY PARAMETERS

group	alloy	adhesive	pretreatm	environm	laboratory	
$g :=$	$A :=$	$B :=$	$C :=$	$D :=$	$L1 :=$	$L2 :=$
1	10	10	10	10	20	10
2	10	10	10	20	10	20
3	10	10	20	10	20	20
4	10	10	20	20	10	10
5	10	20	10	10	20	20
6	10	20	10	20	10	10
7	10	20	20	10	20	10
8	10	20	20	20	10	20
9	20	10	10	10	10	10
10	20	10	10	20	20	20
11	20	10	20	10	10	20
12	20	10	20	20	20	10
13	20	20	10	10	10	20
14	20	20	10	20	20	10
15	20	20	20	10	10	10
16	20	20	20	20	20	20

LOAD LEVEL $S_1 := 0.60$ $S_2 := 0.42$ $S_3 := 0.30$

EXPERIMENTAL RESULTS

 $E := \text{READPRN}(\text{test})$

LOG values of parameters

 $a_i := \log(A_i)$ $b_i := \log(B_i)$ $c_i := \log(C_i)$ $d_i := \log(D_i)$ $l1_i := \log(L1_i)$ $l2_i := \log(L2_i)$ $s_j := \log(S_j)$

REGRESSION COEFFICENTS

$$m0 := -360.276091$$

$$ma := 398.125594 \quad mb := 270.746839 \quad mab := -300.736518$$

$$mc := 302.198053 \quad md := 298.57996$$

$$ms := -6.363824$$

$$mac := -327.058878 \quad mad := -325.467978 \quad mbc := -231.915309$$

$$mbd := -232.017182 \quad mcd := -253.167392$$

$$mabc := 253.093218 \quad mabd := 253.313765 \quad macd := 271.21409$$

$$mbcd := 201.223886 \quad mabcd := -215.429202$$

$$stdv := 0.372051$$

MEAN REGRESSION LINES

$$\log N1_{1,i,j} := m0 + ma \cdot a_i + mb \cdot b_i + mab \cdot a_i \cdot b_i + mc \cdot c_i + md \cdot d_i + ms \cdot s_j$$

$$\log N1_{3,i,j} := mac \cdot a_i \cdot c_i + mad \cdot a_i \cdot d_i + mbc \cdot b_i \cdot c_i + mbd \cdot b_i \cdot d_i + mcd \cdot c_i \cdot d_i$$

$$\log N1_{4,i,j} := mabc \cdot a_i \cdot b_i \cdot c_i + mabd \cdot a_i \cdot b_i \cdot d_i + macd \cdot a_i \cdot c_i \cdot d_i + mbcd \cdot b_i \cdot c_i \cdot d_i + mabcd \cdot a_i \cdot b_i \cdot c_i \cdot d_i$$

$$\log N1_{i,j} := \log N1_{1,i,j} + \log N1_{3,i,j} + \log N1_{4,i,j}$$

$$N1_{i,j} := 10^{\log N1_{i,j}}$$

DESIGN REGRESSION LINES (Mean minus two standard deviations)

$$\log N2_{i,j} := \log N1_{i,j} - 2 \cdot stdv$$

$$N2_{i,j} := 10^{\log N2_{i,j}}$$

NUMBER OF CYCLES FOR EACH SERIE AND LOAD LEVEL

group i	Mean level			Design level		
	0.60 N1 _{i,1}	0.42 N1 _{i,2}	0.30 N1 _{i,3}	0.60 N2 _{i,1}	0.42 N2 _{i,2}	0.30 N2 _{i,3}
1	6897	66747	568020	1243	12032	102391
2	2050	19843	168867	370	3577	30440
3	7698	74496	633967	1388	13429	114278
4	5101	49365	420098	919	8898	75727
5	2093	20254	172362	377	3651	31070
6	2732	26442	225022	493	4766	40562
7	10007	96841	824125	1804	17457	148556
8	11931	115462	982593	2151	20813	177122
9	916546	8869991	75484241	165216	1598900	13606746
10	8953	86643	737335	1614	15618	132912
11	23032	222896	1896858	4152	40179	341927
12	16673	161351	1373109	3005	29085	247516
13	36300	351296	2989549	6543	63324	538894
14	16818	162757	1385076	3032	29339	249673
15	41627	402847	3428253	7504	72617	617975
16	9966	96449	820786	1796	17386	147954

slope and level of S-N curve

Mean

Design

Slope

$$m1_i = \frac{\log\left(\frac{N1_{i,3}}{N1_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

$$m2_i = \frac{\log\left(\frac{N2_{i,3}}{N2_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

Constant

$$C1_i = N1_{i,1} \cdot (S_1)^{m1_i}$$

$$C2_i = N2_{i,1} \cdot (S_1)^{m2_i}$$

Level at 2 million cycles

$$L1_{2m_i} = \left[\frac{C1_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m1_i} \right)}$$

$$L2_{2m_i} = \left[\frac{C2_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m2_i} \right)}$$

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III-4

SLOPE, CONSTANT, NUMBER OF CYCLES AT MEAN LEVEL AND AT 2 MILLION CYCLES

Mean					Design			
i	m1 _i	C1 _i	N1 _{i,2}	L1_2m _i	m2 _i	C2 _i	N2 _{i,2}	L2_2m _i
1	6.364	267	66747	0.246	6.364	48	12032	0.188
2	6.364	79	19843	0.203	6.364	14	3577	0.155
3	6.364	298	74496	0.25	6.364	54	13429	0.191
4	6.364	198	49365	0.235	6.364	36	8898	0.179
5	6.364	81	20254	0.204	6.364	15	3651	0.156
6	6.364	106	26442	0.213	6.364	19	4766	0.163
7	6.364	388	96841	0.261	6.364	70	17457	0.199
8	6.364	462	115462	0.268	6.364	83	20813	0.205
9	6.364	35510	8869991	0.531	6.364	6401	1598900	0.405
10	6.364	347	86643	0.256	6.364	63	15618	0.196
11	6.364	892	222896	0.298	6.364	161	40179	0.227
12	6.364	646	161351	0.283	6.364	116	29085	0.216
13	6.364	1406	351296	0.32	6.364	254	63324	0.244
14	6.364	652	162757	0.283	6.364	117	29339	0.216
15	6.364	1613	402847	0.327	6.364	291	72617	0.249
16	6.364	386	96449	0.261	6.364	70	17386	0.199

index k = 1..8 p = 1..4

Influence factor air/water at mean level

$$T_k = 2 \cdot k - 1 \quad N_k = 2 \cdot k \quad f1_{aw_k} = \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

Average

arithmetic

$$\frac{\sum_k f1_{aw_k}}{8} = 14.571$$

geometrical

$$\left(\prod_k f1_{aw_k} \right)^{\frac{1}{8}} = 2.834$$

T _k	N _k	f1 _{aw_k}
1	2	3.364
3	4	1.509
5	6	0.766
7	8	0.839
9	10	102.374
11	12	1.381
13	14	2.158
15	16	4.177

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III-5

Influence factor pretreatment at mean level

$$T_1 := 1 \quad T_2 := 2 \quad T_3 := 5 \quad T_4 := 6 \quad T_5 := 9 \quad T_6 := 10 \quad T_7 := 13 \quad T_8 := 14$$

$$N_1 := 3 \quad N_2 := 4 \quad N_3 := 7 \quad N_4 := 8 \quad N_5 := 11 \quad N_6 := 12 \quad N_7 := 15 \quad N_8 := 16$$

$$f1_DCC_k := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

$$\frac{\sum_k f1_DCC_k}{8} = 5.578$$

$$\left(\prod_k f1_DCC_k \right)^{\frac{1}{8}} = 0.926$$

T_k	N_k	$f1_DCC_k$
1	3	0.896
2	4	0.402
5	7	0.209
6	8	0.229
9	11	39.794
10	12	0.537
13	15	0.872
14	16	1.687

Relative influence factor specimen at mean level

Specimen type 1 (6061-T6 / 9323)

$$f1_1_p = \frac{4 \cdot N1_{p,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_1_p}{4} = 0.285 \quad \left(\prod_p f1_1_p \right)^{\frac{1}{4}} = 0.191$$

Specimen type 2 (6061-T6 / 7823)

$$f1_2_p = \frac{4 \cdot N1_{p+4,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_2_p}{4} = 0.486 \quad \left(\prod_p f1_2_p \right)^{\frac{1}{4}} = 0.202$$

Specimen type 3 (5754-WH / 9323)

$$f1_3_p = \frac{4 \cdot N1_{p+8,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_3_p}{4} = 1.907 \quad \left(\prod_p f1_3_p \right)^{\frac{1}{4}} = 1.662$$

Specimen type 4 (5754-WH / 7823)

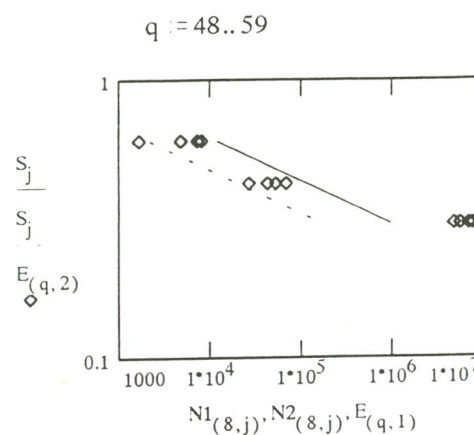
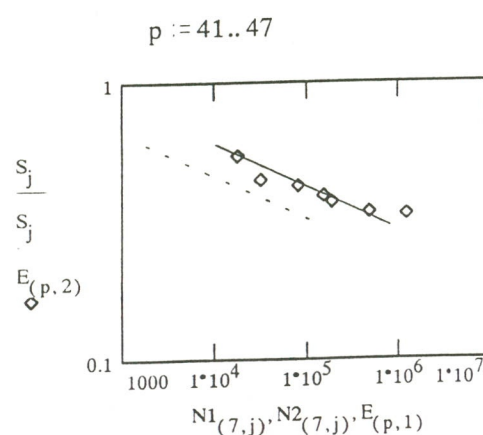
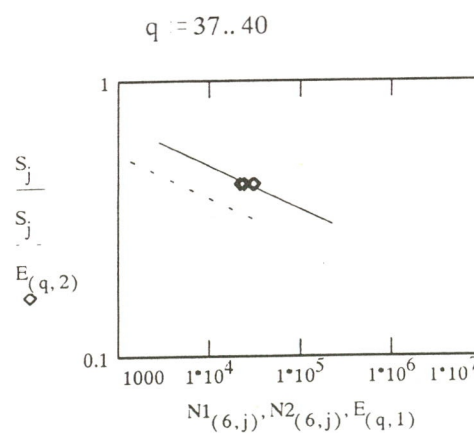
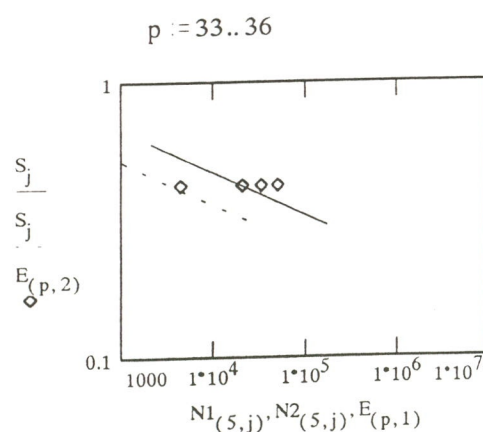
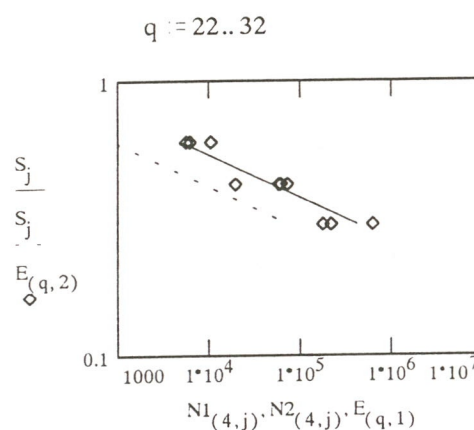
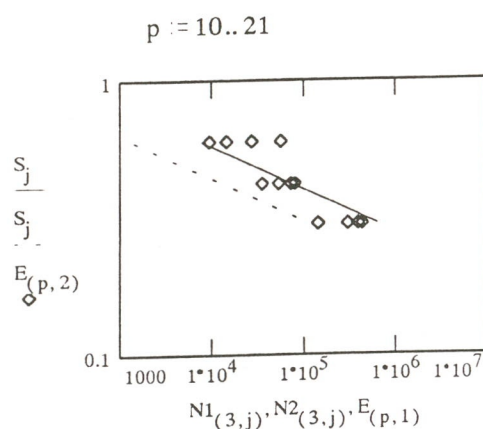
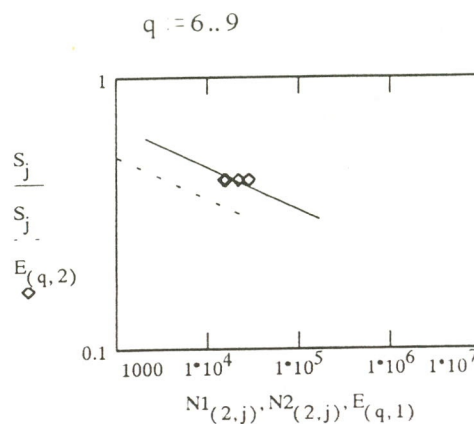
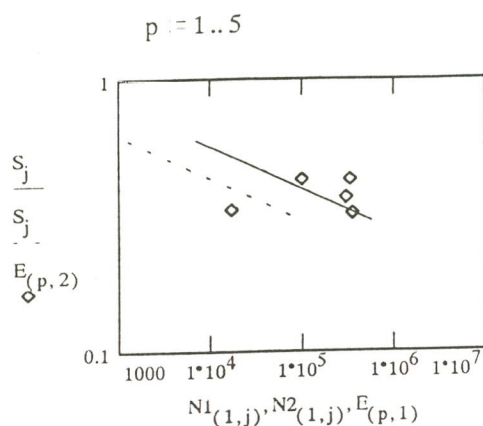
$$f1_4_p = \frac{4 \cdot N1_{p+12,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_4_p}{4} = 1.322 \quad \left(\prod_p f1_4_p \right)^{\frac{1}{4}} = 0.885$$

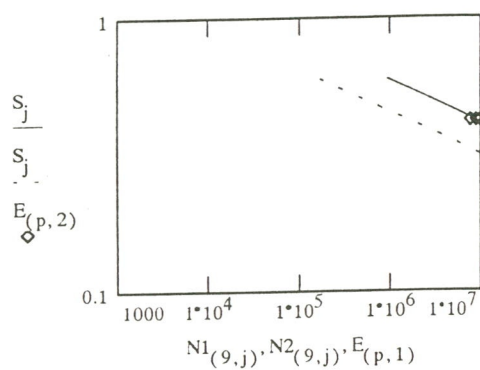
Overview

$f1_1_p$	$f1_2_p$	$f1_3_p$	$f1_4_p$
0.029	0.009	3.812	0.151
0.268	0.358	1.172	2.202
0.374	0.486	1.119	2.022
0.467	1.093	1.527	0.913

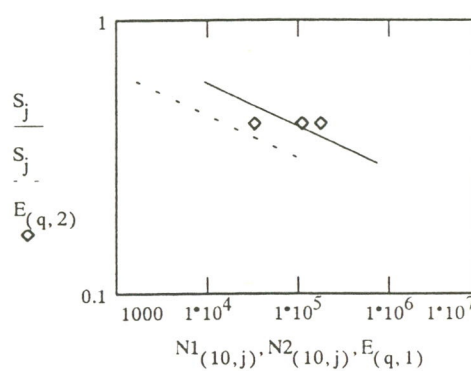
S-N curves and experimental results per group



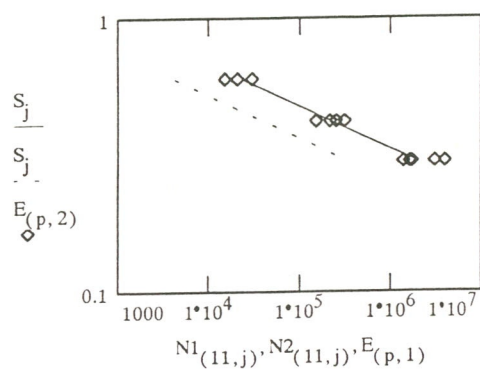
p := 60..62



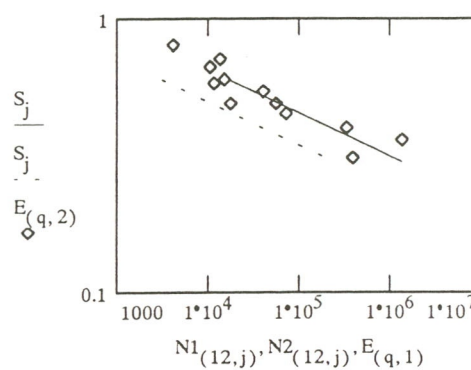
q := 63..65



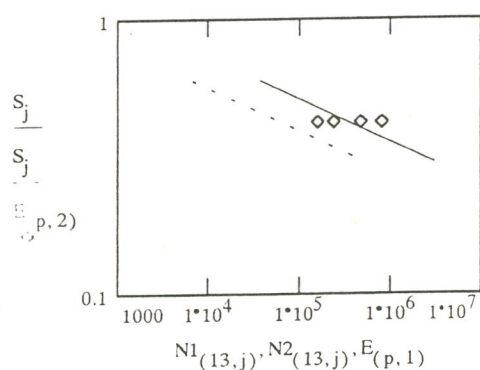
p := 66..78



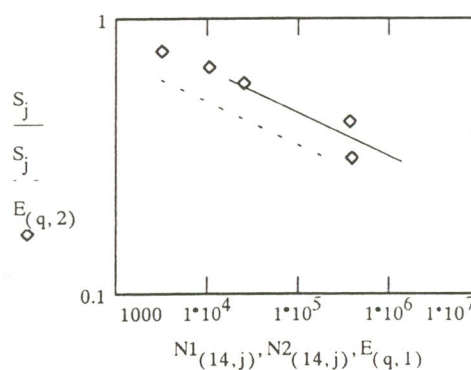
q := 79..90



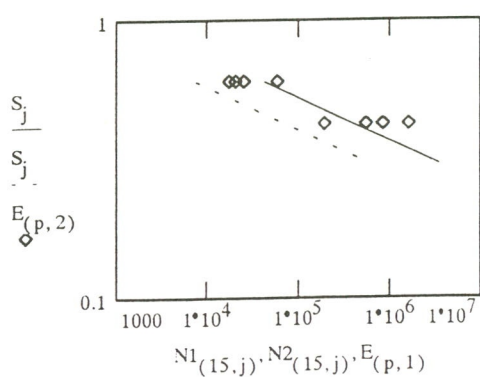
p := 91..94



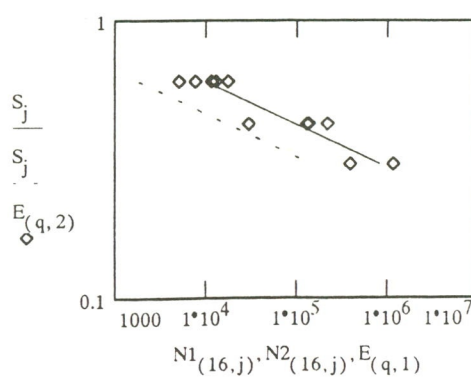
q := 95..99



p := 100..107



q := 108..118



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Multi regression analysis for aluminium bonded joints

IV-1

ANALYSIS IV

ORIGIN := 1

index i := 1..16 j := 1..3

DUMMY PARAMETERS

group	alloy	adhesive	pretreatm	environm	laboratory	
g :=	A :=	B :=	C :=	D :=	L1 :=	L2 :=

LOAD LEVEL $S_1 := 0.60$ $S_2 := 0.42$ $S_3 := 0.30$

EXPERIMENTAL RESULTS

E := READPRN(test)

LOG values of parameters

$$a_i := \log(A_i)$$

$$b_i := \log(B_i)$$

$$c_i := \log(C_i)$$

$$d_i := \log(D_i)$$

$$l1_i := \log(L1_i)$$

$$l2_i := \log(L2_i)$$

$$s_j := \log(S_j)$$

REGRESSION COEFFICIENTS

$m0 := -179.444972$
 $ma := 268.017243$ $mb := 185.750461$ $mab := -245.267737$
 $mc := 177.230005$ $md := 206.564141$
 $ms := 120.955895$
 $mac := -234.567365$ $mad := -259.568149$ $mbc := -167.119516$
 $mbd := -182.756117$ $mcd := -178.019736$
 $mabc := 206.839843$ $mabd := 221.784626$ $macd := 214.923523$
 $mbcd := 149.071597$ $mabcd := -177.296203$
 $msa := -80.894883$ $msb := 26.656074$ $msc := -81.462005$ $msd := 35.501237$
 $msab := -38.793197$ $msac := 61.323429$ $msad := -37.747798$
 $msbd := -70.927524$ $msabd := 67.699509$
 $stdv := 0.29614$

MEAN REGRESSION LINES

$\log N1_{1,i,j} := m0 + ma \cdot a_i + mb \cdot b_i + mab \cdot a_i \cdot b_i + mc \cdot c_i + md \cdot d_i + ms \cdot s_j$
 $\log N1_{3,i,j} := mac \cdot a_i \cdot c_i + mad \cdot a_i \cdot d_i + mbc \cdot b_i \cdot c_i + mbd \cdot b_i \cdot d_i + mcd \cdot c_i \cdot d_i$
 $\log N1_{4,i,j} := mabc \cdot a_i \cdot b_i \cdot c_i + mabd \cdot a_i \cdot b_i \cdot d_i + macd \cdot a_i \cdot c_i \cdot d_i + mbcd \cdot b_i \cdot c_i \cdot d_i + mabcd \cdot a_i \cdot b_i \cdot c_i \cdot d_i$
 $\log N1_{5,i,j} := msa \cdot s_j \cdot a_i + msb \cdot s_j \cdot b_i + msc \cdot s_j \cdot c_i + msd \cdot s_j \cdot d_i$
 $\log N1_{6,i,j} := msab \cdot s_j \cdot a_i \cdot b_i + msac \cdot s_j \cdot a_i \cdot c_i + msad \cdot s_j \cdot a_i \cdot d_i$
 $\log N1_{7,i,j} := msbd \cdot s_j \cdot b_i \cdot d_i + msabd \cdot s_j \cdot a_i \cdot b_i \cdot d_i$
 $\log N1_{i,j} = \log N1_{1,i,j} + \log N1_{3,i,j} + \log N1_{4,i,j} + \log N1_{5,i,j} + \log N1_{6,i,j} + \log N1_{7,i,j}$
 $N1_{i,j} = 10^{\log N1_{i,j}}$

DESIGN REGRESSION LINES (Mean minus two standard deviations)

$\log N2_{i,j} := \log N1_{i,j} - 2 \cdot stdv$
 $N2_{i,j} = 10^{\log N2_{i,j}}$

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IV-3

NUMBER OF CYCLES FOR EACH SERIE AND LOAD LEVEL

group i	Mean level			Design level		
	0.60 N1 _{i,1}	0.42 N1 _{i,2}	0.30 N1 _{i,3}	0.60 N2 _{i,1}	0.42 N2 _{i,2}	0.30 N2 _{i,3}
1	425608	186669	85784	108825	47730	21935
2	25134	19843	15877	6427	5074	4060
3	19203	73197	258644	4910	18716	66134
4	6936	47592	292794	1774	12169	74866
5	8871	20254	44130	2268	5179	11284
6	5796	26442	110685	1482	6761	28302
7	4406	87429	1464752	1127	22355	374528
8	2991	118577	3816580	765	30319	975875
9	957108	8869978	72462563	244726	2267997	18528220
10	13675	86643	494451	3497	22154	126428
11	19934	221219	2142120	5097	56564	547727
12	18514	140465	950146	4734	35916	242946
13	18535	351295	5636136	4739	89824	1441124
14	18655	138852	922451	4770	35504	235865
15	27182	616915	11731826	6950	157741	2999754
16	10572	94228	741994	2703	24094	189723

slope and level of S-N curve

Mean

Design

Slope

$$m1_i = \frac{\log\left(\frac{N1_{i,3}}{N1_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

$$m2_i = \frac{\log\left(\frac{N2_{i,3}}{N2_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

Constant

$$C1_i = N1_{i,1} \cdot (S_1)^{m1_i}$$

$$C2_i = N2_{i,1} \cdot (S_1)^{m2_i}$$

Level at 2 million cycles

$$L1_{2m_i} = \left[\frac{C1_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m1_i} \right)}$$

$$L2_{2m_i} = \left[\frac{C2_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m2_i} \right)}$$

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SLOPE, CONSTANT, NUMBER OF CYCLES AT MEAN LEVEL AND AT 2 MILLION CYCLES

Mean					Design			
i	m1 _i	C1 _i	N1 _{i,2}	L1_2m _i	m2 _i	C2 _i	N2 _{i,2}	L2_2m _i
1	-2.311	1385620	186669	1.172	-2.311	354294	47730	2.115
2	-0.663	35261	19843	442.842	-0.663	9016	5074	3466.991
3	3.752	2825	73197	0.174	3.752	722	18716	0.121
4	5.4	440	47592	0.21	5.4	112	12169	0.163
5	2.315	2719	20254	0.058	2.315	695	5179	0.032
6	4.255	659	26442	0.152	4.255	169	6761	0.11
7	8.377	61	87429	0.289	8.377	16	22355	0.246
8	10.317	15	118577	0.319	10.317	4	30319	0.28
9	6.242	39454	8869978	0.533	6.242	10088	2267997	0.429
10	5.176	972	86643	0.229	5.176	248	22154	0.176
11	6.748	635	221219	0.303	6.748	162	56564	0.248
12	5.681	1016	140465	0.263	5.681	260	35916	0.207
13	8.248	274	351295	0.34	8.248	70	89824	0.288
14	5.628	1053	138852	0.261	5.628	269	35504	0.205
15	8.754	311	616915	0.367	8.754	79	157741	0.314
16	6.133	461	94228	0.255	6.133	118	24094	0.204

index k := 1..8 p := 1..4

Influence factor air/water at mean level

$$T_k := 2 \cdot k - 1 \quad N_k := 2 \cdot k \quad f1_{aw_k} := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

Average

arithmetic

$$\frac{\sum_k f1_{aw_k}}{8} = 15.684$$

geometrical

$$\left(\prod_k f1_{aw_k} \right)^{\frac{1}{8}} = 3.486$$

T _k	N _k	f1 _{aw_k}
1	2	9.407
3	4	1.538
5	6	0.766
7	8	0.737
9	10	102.374
11	12	1.575
13	14	2.53
15	16	6.547

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IV-5

Influence factor pretreatment at mean level

$$T_1 := 1 \quad T_2 := 2 \quad T_3 := 5 \quad T_4 := 6 \quad T_5 := 9 \quad T_6 := 10 \quad T_7 := 13 \quad T_8 := 14$$

$$N_1 := 3 \quad N_2 := 4 \quad N_3 := 7 \quad N_4 := 8 \quad N_5 := 11 \quad N_6 := 12 \quad N_7 := 15 \quad N_8 := 16$$

$$f1_DCC_k = \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

$$\frac{\sum_k f1_DCC_k}{8} = 5.772$$

$$\left(\prod_k f1_DCC_k \right)^{\frac{1}{8}} = 1.017$$

T_k	N_k	$f1_DCC_k$
1	3	2.55
2	4	0.417
5	7	0.232
6	8	0.223
9	11	40.096
10	12	0.617
13	15	0.569
14	16	1.474

Relative influence factor specimen at mean level**Specimen type 1 (6061-T6 / 9323)**

$$f1_{-1_p} = \frac{4 \cdot N1_{p,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_{-1_p}}{p} = 0.285 \quad \left(\prod_p f1_{-1_p} \right)^{\frac{1}{4}} = 0.238$$

Specimen type 2 (6061-T6 / 7823)

$$f1_{-2_p} = \frac{4 \cdot N1_{p+4,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_{-2_p}}{4} = 0.483 \quad \left(\prod_p f1_{-2_p} \right)^{\frac{1}{4}} = 0.193$$

Specimen type 3 (5754-WH / 9323)

$$f1_{-3_p} = \frac{4 \cdot N1_{p+8,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_{-3_p}}{4} = 1.831 \quad \left(\prod_p f1_{-3_p} \right)^{\frac{1}{4}} = 1.562$$

Specimen type 4 (5754-WH / 7823)

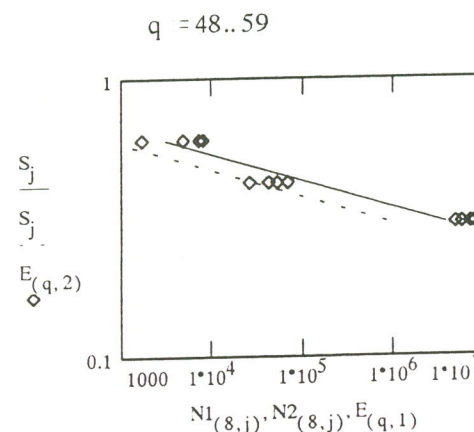
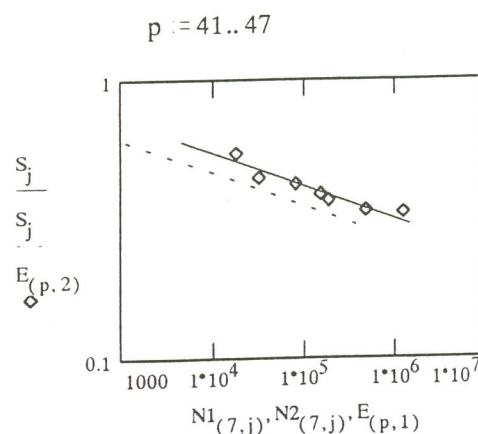
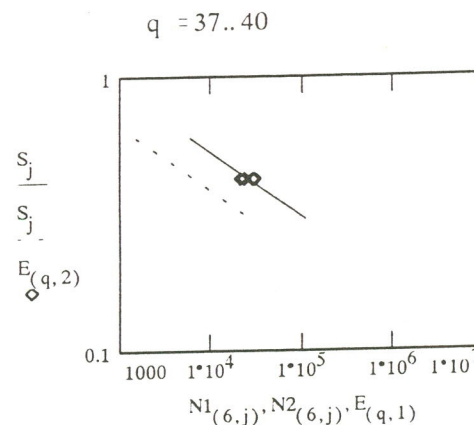
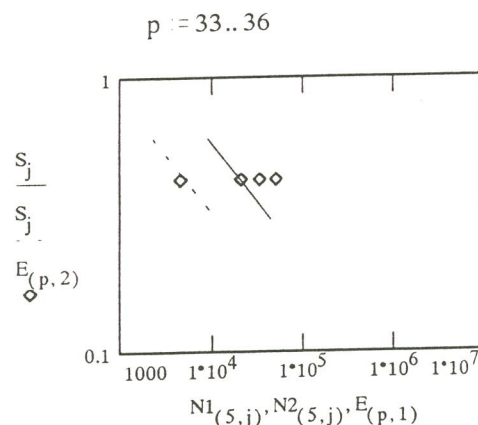
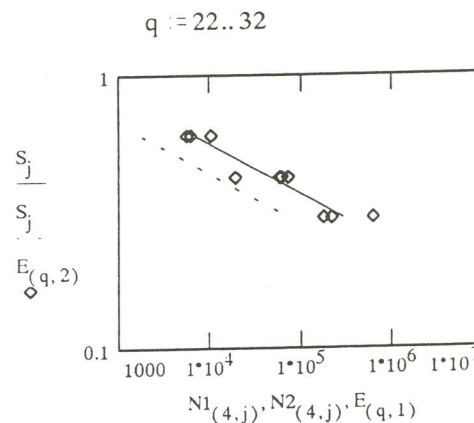
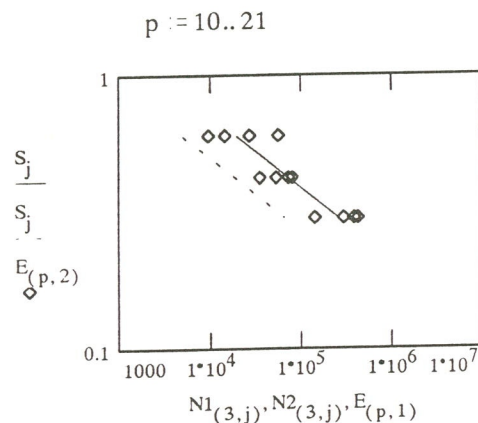
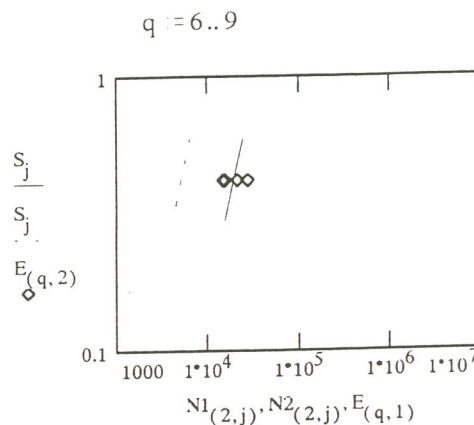
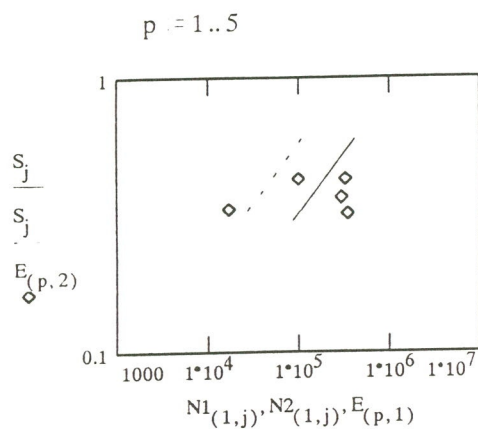
$$f1_{-4_p} = \frac{4 \cdot N1_{p+12,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_{-4_p}}{4} = 1.401 \quad \left(\prod_p f1_{-4_p} \right)^{\frac{1}{4}} = 0.917$$

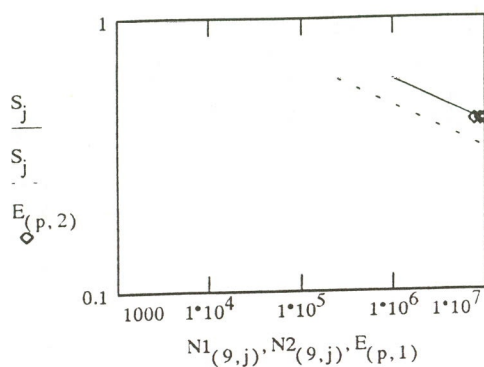
Overview

$f1_{-1_p}$	$f1_{-2_p}$	$f1_{-3_p}$	$f1_{-4_p}$
0.079	0.009	3.763	0.149
0.292	0.389	1.275	2.044
0.293	0.35	0.886	2.471
0.475	1.183	1.402	0.94

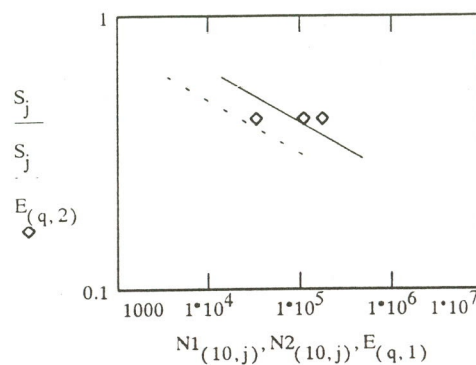
S-N curves and experimental results per group



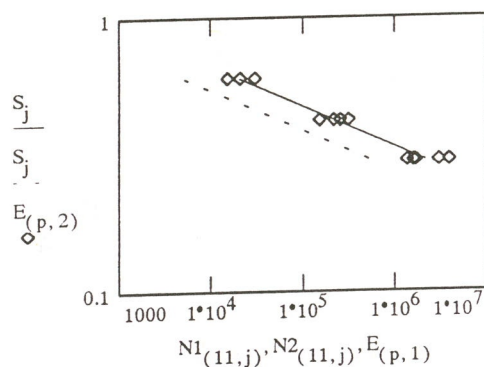
$p := 60..62$



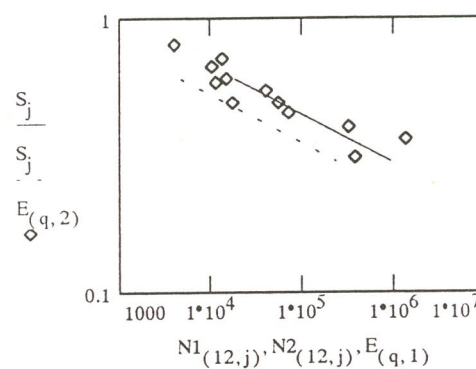
$q := 63..65$



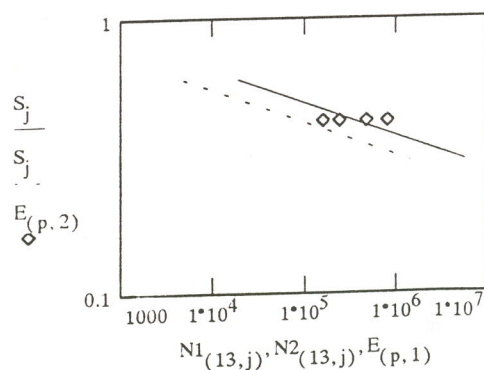
$p := 66..78$



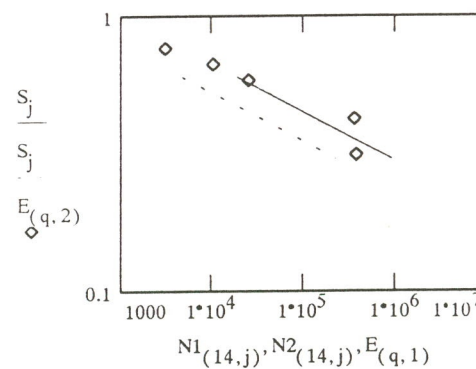
$q := 79..90$



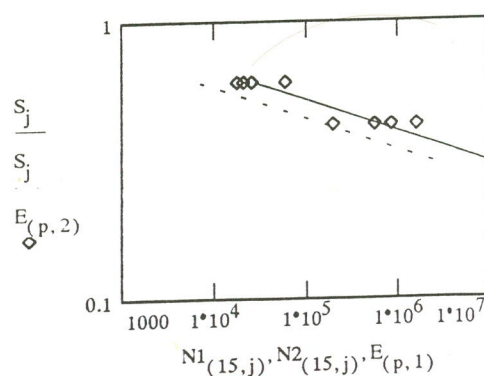
$p := 91..94$



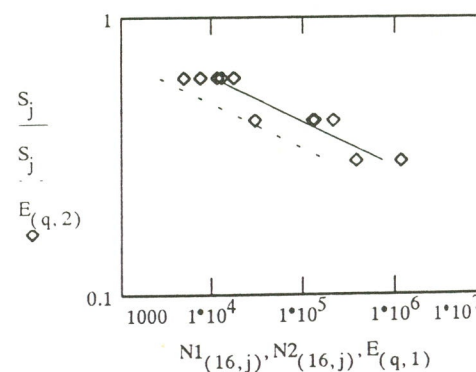
$q := 95..99$



$p := 100..107$



$q := 108..118$



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V-1

Multi regression analysis for aluminium bonded joints

ANALYSIS V

ORIGIN := 1

index i := 1..16 j := 1..3

DUMMY PARAMETERS

group	alloy	adhesive	pretreatm	environm	laboratory	
g :=	A :=	B :=	C :=	D :=	L1 :=	L2 :=

LOAD LEVEL $S_1 := 0.60$ $S_2 := 0.42$ $S_3 := 0.30$

EXPERIMENTAL RESULTS

E := READPRN(test)

LOG values of parameters

 $a_i := \log(A_i)$ $b_i := \log(B_i)$ $c_i := \log(C_i)$ $d_i := \log(D_i)$ $l1_i := \log(L1_i)$ $l2_i := \log(L2_i)$ $s_j := \log(S_j)$

REGRESSION COEFFICENTS

$m0 = 788.439254$
 $ma = -304.410553$ $mb = -285.364088$ $mab = -7.295395$
 $mc = -293.884543$ $md = -289.396708$
 $ms = 120.955895$
 $ml1 = -74.887306$ $ml2 = -32.441225$ $ml1l2 = 31.132498$
 $mac = 3.404977$ $mbc = 242.361933$
 $mbd = -11.247009$ $mcd = -6.510627$
 $mabd = 221.784626$ $macd = 214.923523$
 $mabcd = -177.296203$
 $msa = -80.894883$ $msb = 26.656074$ $msc = -81.462005$ $msd = 35.501237$
 $msab = -38.793197$ $msac = 61.323429$ $msad = -37.747798$
 $msbd = -70.927524$ $msabd = 67.699509$
 $stdv = 0.29614$

MEAN REGRESSION LINES

$\log N1_{1,i,j} = m0 + ma \cdot a_i + mb \cdot b_i + mab \cdot a_i \cdot b_i + mc \cdot c_i + md \cdot d_i + ms \cdot s_j$
 $\log N1_{2,i,j} = ml1 \cdot l1_i + ml2 \cdot l2_i + ml1l2 \cdot l1_i \cdot l2_i$
 $\log N1_{3,i,j} = mac \cdot a_i \cdot c_i + mbc \cdot b_i \cdot c_i + mbd \cdot b_i \cdot d_i + mcd \cdot c_i \cdot d_i$
 $\log N1_{4,i,j} = mabd \cdot a_i \cdot b_i \cdot d_i + macd \cdot a_i \cdot c_i \cdot d_i + mabcd \cdot a_i \cdot b_i \cdot c_i \cdot d_i$
 $\log N1_{5,i,j} = msa \cdot s_j \cdot a_i + msb \cdot s_j \cdot b_i + msc \cdot s_j \cdot c_i + msd \cdot s_j \cdot d_i$
 $\log N1_{6,i,j} = msab \cdot s_j \cdot a_i \cdot b_i + msac \cdot s_j \cdot a_i \cdot c_i + msad \cdot s_j \cdot a_i \cdot d_i$
 $\log N1_{7,i,j} = msbd \cdot s_j \cdot b_i \cdot d_i + msabd \cdot s_j \cdot a_i \cdot b_i \cdot d_i$
 $\log N1_{i,j} = \log N1_{1,i,j} + \log N1_{2,i,j} + \log N1_{3,i,j} + \log N1_{4,i,j} + \log N1_{5,i,j} + \log N1_{6,i,j} + \log N1_{7,i,j}$
 $N1_{i,j} = 10^{\log N1_{i,j}}$

DESIGN REGRESSION LINES (Mean minus two standard deviations)

$\log N2_{i,j} = \log N1_{i,j} - 2 \cdot stdv$
 $N2_{i,j} = 10^{\log N2_{i,j}}$

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V-3

NUMBER OF CYCLES FOR EACH SERIE AND LOAD LEVEL

group i	Mean level			Design level		
	0.60 N1 _{i,1}	0.42 N1 _{i,2}	0.30 N1 _{i,3}	0.60 N2 _{i,1}	0.42 N2 _{i,2}	0.30 N2 _{i,3}
1	425608	186669	85785	108825	47730	21935
2	25134	19843	15877	6427	5074	4060
3	19203	73197	258645	4910	18716	66134
4	6936	47592	292795	1774	12169	74866
5	8871	20254	44130	2268	5179	11284
6	5796	26442	110686	1482	6761	28302
7	4406	87430	1464755	1127	22355	374529
8	2991	118578	3816590	765	30320	975878
9	957110	8869997	72462720	244727	2268002	18528260
10	13675	86643	494452	3497	22154	126428
11	19934	221220	2142127	5097	56564	547728
12	18514	140466	950150	4734	35916	242947
13	18535	351295	5636144	4739	89824	1441126
14	18655	138853	922454	4770	35504	235866
15	27182	616917	11731867	6950	157742	2999764
16	10572	94228	741997	2703	24094	189724

slope and level of S-N curve

Mean

Design

Slope

$$m1_i := \frac{\log\left(\frac{N1_{i,3}}{N1_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

$$m2_i := \frac{\log\left(\frac{N2_{i,3}}{N2_{i,1}}\right)}{\log\left(\frac{S_1}{S_3}\right)}$$

Constant

$$C1_i := N1_{i,1} \cdot (S_1)^{m1_i}$$

$$C2_i := N2_{i,1} \cdot (S_1)^{m2_i}$$

Level at 2 million cycles

$$L1_{2m_i} := \left[\frac{C1_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m1_i} \right)}$$

$$L2_{2m_i} := \left[\frac{C2_i}{(2 \cdot 10^6)} \right]^{\left(\frac{1}{m2_i} \right)}$$

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SLOPE, CONSTANT, NUMBER OF CYCLES AT MEAN LEVEL AND AT 2 MILLION CYCLES

Mean					Design			
i	m1 _i	C1 _i	N1 _{i,2}	L1_2m _i	m2 _i	C2 _i	N2 _{i,2}	L2_2m _i
1	-2.311	1385621	186669	1.172	-2.311	354294	47730	2.115
2	-0.663	35261	19843	442.841	-0.663	9016	5074	3466.983
3	3.752	2825	73197	0.174	3.752	722	18716	0.121
4	5.4	440	47592	0.21	5.4	112	12169	0.163
5	2.315	2719	20254	0.058	2.315	695	5179	0.032
6	4.255	659	26442	0.152	4.255	169	6761	0.11
7	8.377	61	87430	0.289	8.377	16	22355	0.246
8	10.317	15	118578	0.319	10.317	4	30320	0.28
9	6.242	39454	8869997	0.533	6.242	10088	2268002	0.429
10	5.176	972	86643	0.229	5.176	248	22154	0.176
11	6.748	635	221220	0.303	6.748	162	56564	0.248
12	5.681	1016	140466	0.263	5.681	260	35916	0.207
13	8.248	274	351295	0.34	8.248	70	89824	0.288
14	5.628	1053	138853	0.261	5.628	269	35504	0.205
15	8.754	311	616917	0.367	8.754	79	157742	0.314
16	6.133	461	94228	0.255	6.133	118	24094	0.204

index k:=1..8 p:=1..4

Influence factor air/water at mean level

$$T_k = 2 \cdot k - 1 \quad N_k = 2 \cdot k \quad f1_{aw_k} = \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

Average

arithmetic

$$\frac{\sum_k f1_{aw_k}}{8} = 15.684$$

geometrical

$$\left(\prod_k f1_{aw_k} \right)^{\frac{1}{8}} = 3.486$$

T _k	N _k	f1 _{aw_k}
1	2	9.407
3	4	1.538
5	6	0.766
7	8	0.737
9	10	102.374
11	12	1.575
13	14	2.53
15	16	6.547

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Influence factor pretreatment at mean level

$$T_1 := 1 \quad T_2 := 2 \quad T_3 := 5 \quad T_4 := 6 \quad T_5 := 9 \quad T_6 := 10 \quad T_7 := 13 \quad T_8 := 14$$

$$N_1 := 3 \quad N_2 := 4 \quad N_3 := 7 \quad N_4 := 8 \quad N_5 := 11 \quad N_6 := 12 \quad N_7 := 15 \quad N_8 := 16$$

$$f1_DCC_k := \frac{N1_{T_k,2}}{N1_{N_k,2}}$$

$$\frac{\sum_k f1_DCC_k}{8} = 5.772$$

$$\left(\prod_k f1_DCC_k \right)^{\frac{1}{8}} = 1.017$$

T_k	N_k	$f1_DCC_k$
1	3	2.55
2	4	0.417
5	7	0.232
6	8	0.223
9	11	40.096
10	12	0.617
13	15	0.569
14	16	1.474

Relative influence factor specimen at mean level**Specimen type 1 (6061-T6 / 9323)**

$$f1_1_p := \frac{4 \cdot N1_{p,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_1_p}{4} = 0.285 \quad \left(\prod_p f1_1_p \right)^{\frac{1}{4}} = 0.238$$

Specimen type 3 (5754-WH / 9323)

$$f1_3_p := \frac{4 \cdot N1_{p+8,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_3_p}{4} = 1.831 \quad \left(\prod_p f1_3_p \right)^{\frac{1}{4}} = 1.562$$

Specimen type 2 (6061-T6 / 7823)

$$f1_2_p := \frac{4 \cdot N1_{p+4,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

$$\frac{\sum_p f1_2_p}{4} = 0.483 \quad \left(\prod_p f1_2_p \right)^{\frac{1}{4}} = 0.193$$

Specimen type 4 (5754-WH / 7823)

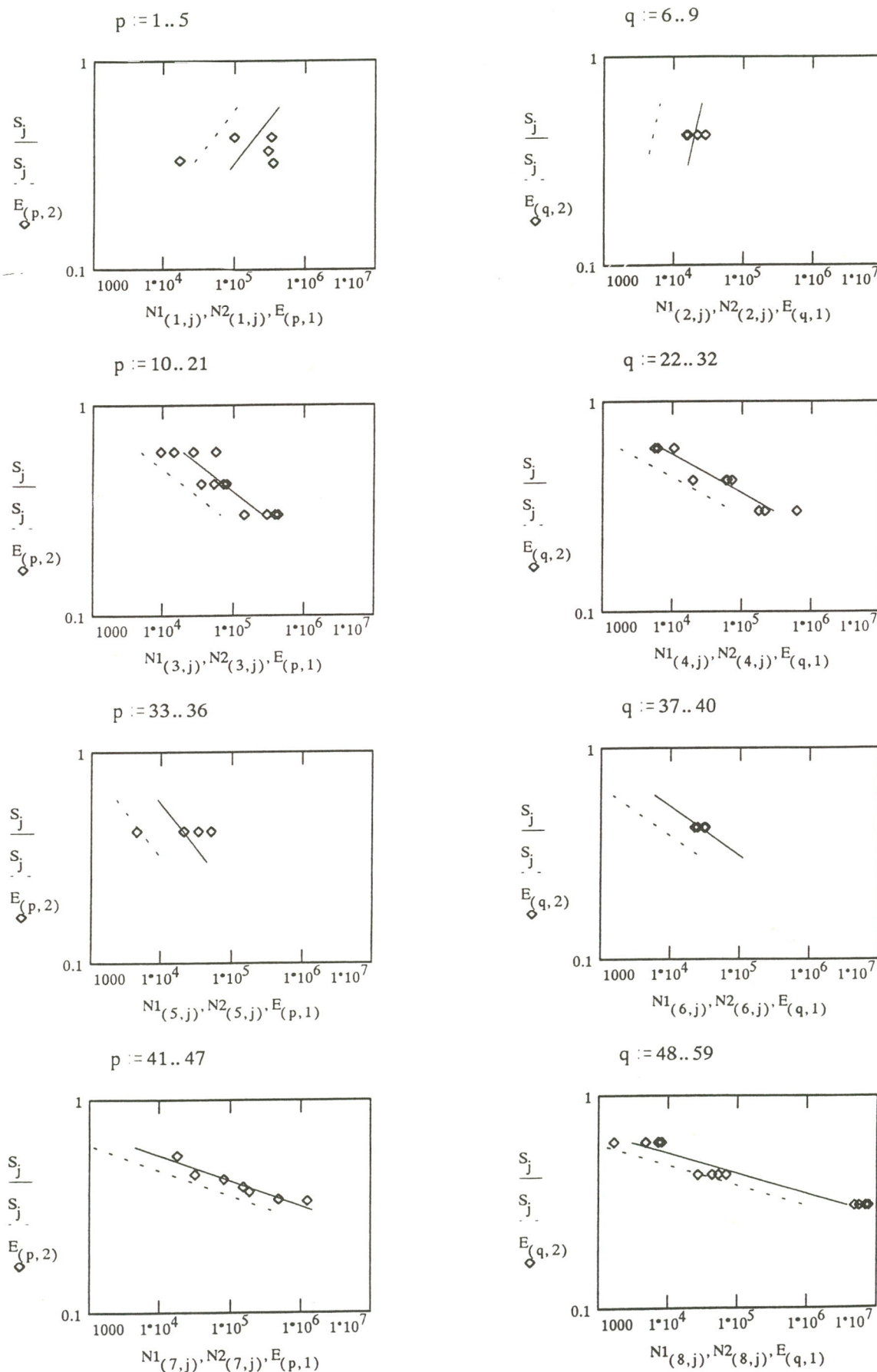
$$f1_4_p := \frac{4 \cdot N1_{p+12,2}}{N1_{p,2} + N1_{p+4,2} + N1_{p+8,2} + N1_{p+12,2}}$$

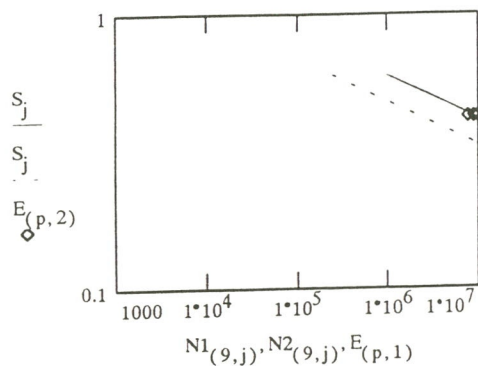
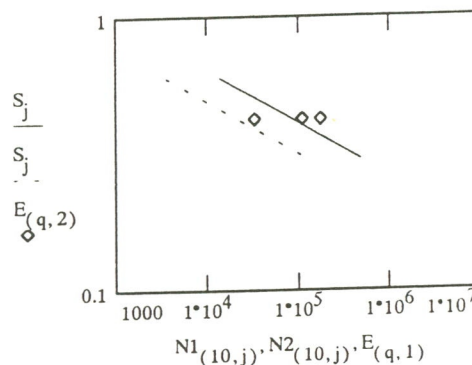
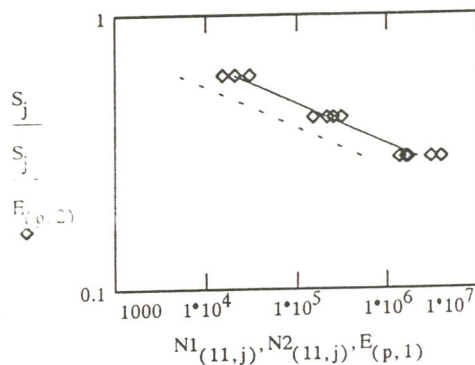
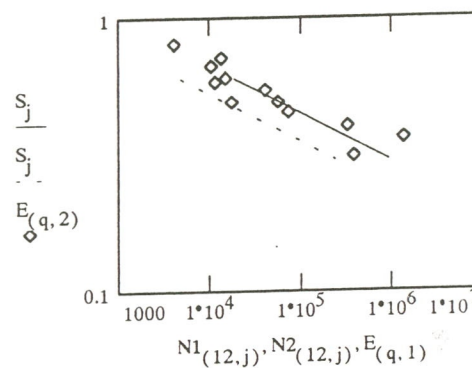
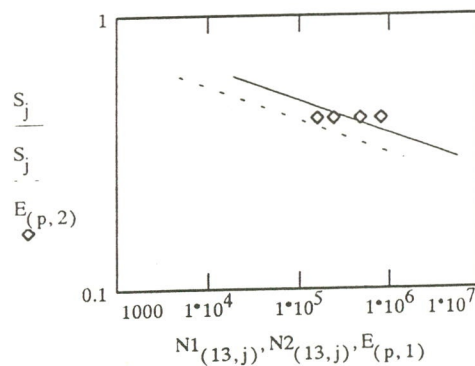
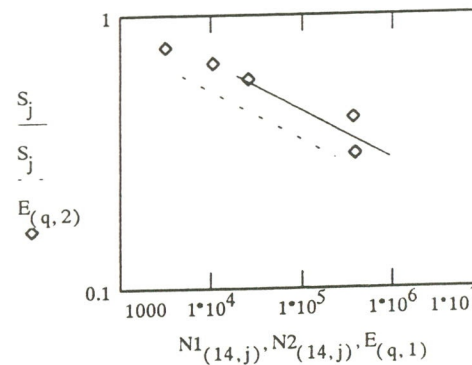
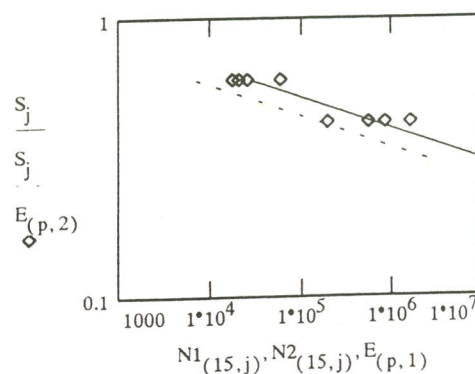
$$\frac{\sum_p f1_4_p}{4} = 1.401 \quad \left(\prod_p f1_4_p \right)^{\frac{1}{4}} = 0.917$$

Overview

$f1_1_p$	$f1_2_p$	$f1_3_p$	$f1_4_p$
0.079	0.009	3.763	0.149
0.292	0.389	1.275	2.044
0.293	0.35	0.886	2.471
0.475	1.183	1.402	0.94

S-N curves and experimental results per group



$p := 60..62$  $q := 63..65$  $p := 66..78$  $q := 79..90$  $p := 91..94$  $q := 95..99$  $p := 100..107$  $q := 108..118$ 