19. On the influence of cyclic stress-strain curves, damage parameters, and various evaluation concepts on the life prediction by the local approach

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In the last years, several larger investigations were undertaken to evaluate the efficiency of various concepts for the fatigue crack initiation life prediction /1, 2, 3/. These concepts can be divided into two groups: the first one uses nominal stress-life curves, any cycle counting method and the Miner rule. This group can be characterized by the notion nominal approach. The second group, often characterized by the notion local approach, is topic of this paper and should first be explained in detail.

The basic scheme of the local approach is shown in figure 1:

Load history, material constants and the notch factor k_t are the input data. The first module deals with the relationship between the applied load and the local stress-strain behaviour. The second module deals with the material stress-strain behaviour. Both modules are necessary for calculating the local stress-strain history of the notch root. The application of the third module which concerns the material damage and failure behaviour to that local stress-strain history results in the crack initiation life prediction. It is assumed, that the notch root element behaves like a smooth specimen, in other words, that transferability is given.

A generally valid statement upon the efficiency of the different life prediction concepts cannot be given today especially because the investigations were always concerned with very special load histories and components.

Recently, a company of the German airplane industry started a large program /4/ to compare the different concepts by the aid of five flight by flight histories, two of them on two load levels. Thus, seven service fatigue life results are the base of the comparison. The component was a specimen with circular hole. The notch factor is 2.5. All specimens were made out of one plate of an aluminum alloy.

On the left side of figure 2, the first results of the predictions according to the local approach are shown. On the logarithmic x-axis, the related lives are depicted, that is the calculated life over the experimental life. If the calculated life were equal to the experimental one, the relation would be one. Points on the left side of 1 means safe life prediction, points on the right side means unsafe prediction. Each point thus shows the prediction accuracy of one history on a defined load level. As just mentioned, seven predictions were possible. In the plot, the distribution of all seven predictions is shown. On the y-axis, the probability p is depicted. Assuming logarithmic normal distribution, the points should lie on a straight line. This line can be described by the estimated mean value at 50 % probability, and by the slope. Instead of the slope, the value T is given here which is an adequate measure for the scatter. It is determined as the relation between the estimated values of 10 % and 90 %, respectively. In this first prediction, the mean value is .35 and the scatter value T equals 5.7. The dashed regression line of that first prediction will in the next figures always serve as comparison line.

On the right side of figure 2, the results of the nominal approach are depicted additionally. Whereas the local approach lies on the safe side with a factor of nearly 3, the nominal approach mean value only differs by a factor of about 2, but it lies on the unsafe side. The scatter of the nominal approach is a little bit smaller than the one of the local approach. In this context it must be mentioned that in the nominal approach the Rainflow counting method was used to determine load cycles. Rainflow is the very only counting method able to find exactly the cycles the material is subjected to during its service life. Predictions using a modified range counting method yield less scatter, but lie more on the unsafe side. As any range counting has no physical background, it is thought that the good result with regard to the scatter is accidental.

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The question arose whether the local approach could be improved. The above scheme (figure 1) shows that possible mistakes can arise in the basic input data, in any of the three modules, and in an unsufficient transferability. In the following the influence of these possible sources of inaccuracy on the life prediction will be demonstrated. As to the input data, we first got two small samples of smooth specimens to check already existing cyclic material laws. Since it turned out that the material properties differed very much in the one plate, we got an additional third, very large sample. The first already shown predictions on the left side of figure 2 are based on data of this third sample. The influence of the differences in material properties on the life prediction will be shown when discussing the three modules.

The relation of the applied load and the notch root strain in the first module can be given by measurement, by finite element calculations, or by approximation formulas. We found that the choice of the approximation formula did not influence the predictions in a remarkable degree /5/. This can be explained by the fact that most of the local stress-strain behaviour is elastic. In all predictions presented here we used the Neuber formula.

Since not the total local behaviour is elastic, also the second module has to be discussed. This module contains the material stress-strain behaviour. It is commonly described by the cyclic stress-strain curve and by the material memory. The transient phenomena hardening and softening as well as stress relaxation and creep are not taken into consideration. The aluminum alloy reaches stable behaviour very early, so that hardening must not be considered. Creep is prevented by the fully elastic net section which governs the notch root behaviour in a strain controlled way. The omission of mean stress relaxation effects can perhaps influence the prediction, but the available concepts to take relaxation into account are still too rough. All memory cases are constituent part of the computer program.

The cyclic stress strain plot of the material is shown in figure 3. Stress amplitude are plotted against total strain amplitudes. The bold lines show incremental step test results. The points are stabilized

values from strain controlled fully reversed tests on smooth specimens from the large third sample. As indicated by the incremental step tests, the points should not be described by a single curve, but by different curves with the same slope but different yield stresses. The first predictions which should serve as base of comparison, were calculated with stress-strain curve no.1. The results with curve no. 2 and no. 3 are shown in figure 4. The conclusion can be drawn that changing the yield stress does not influence the prediction to a remarkable extent.

The third module in the basic scheme contains the failure and damage behaviour of the material. This is commonly described by a damage-parameter-life curve which takes mean stress into account, by cycle counting equal to Rainflow, and by the Miner rule. We found in earlier investigations /6/ that the damage parameter after Smith Watson and Topper /7/ is the best one. In figure 5 the parameter values of all three samples of smooth specimens are plotted against cycles to crack initiation. Curve no.1 which describes the results of the third very large sample, was used in the first already presented predictions. In figure 6, the results using damage parameter-life curves no. 2 and 3 of the other two very small samples are shown in comparison. It can be seen that the mean values are shifted in the unsafe direction. The reason is that also the damage parameter life curve is shifted to higher life values. These results indicate that greatest possible care has to be taken when determining fatigue life input data.

From other materials we know that the Smith Watson Topper parameter though being generally seen the best one, can still be improved for a special material. Therefore, we performed strain controlled tests with mean strain, which led to hysteresis loops with stabilized mean stresses (figure 7). The damage parameter values of these tests should lie on the same curve as those of the fully reversed tests. Figure 8 shows that they do not. Derived from these results, a simple modification of the Smith Watson Topper parameter was performed. The result is shown in figure 9. All test data now lie on the curve of the fully reversed tests. A specific evaluation showed that most of the cycles of all histories lie under the endurance limit and that only few cycles fall in the region where the improvement was made. Therefore, the introduction of the improved individual damage parameter was not successful (line no. 4 in figure 6).

The next step of our investigation concerned the prestrain influence. In service life small cycles though lying under the endurance limit of pure constant amplitude tests damage the material. This is taken into account by subjecting the smooth specimens to an initial overstrain before the constant amplitude testing begins. The achievable endurance limit thus depends upon the degree of overstrain. From another aluminum alloy the influence of an adequate prestrain on the endurance limit was estimated. Improvement was so tiny that it is not worth showing. Also in this case only very few cycles fall in the region of the improved endurance limit.

The next try to improve the results was to apply a modified local concept proposed by Haibach and Lehrke /8/. This concept derives the failure data of the material from a nominal S-N-curve. The predictions (line no. 5 in figure 6) lie on the unsafe side because an S-N-curve was used which is unsafe. If applied to a real component, the S-N-curve of which is known, the amplitude transformation seems to be an excellent tool to avoid problems such as size effect, residual stresses, surface conditions, a.s.o.

From the hitherto investigations upon these flight by flight histories, the following conclusions can be drawn:

The variation of approximation formulas as well as of the stress strain curve only weakly influence the prediction, because most of the notch root hysteresis loops are elastic.

Small variations of the endurance limit due to different amounts of prestrain or due to the improvement of the damage parameter did not remarkably improve the predictions. The reason is that only few cycles fall in that region of the life curve which is affected by the variations.

Large deviations in the constant amplitude life curves led to an expected large drift of the mean value. Therefore, great care should be taken to determine accurately especially the damage parameter life curve. Such large scatter in the fatigue properties of the material of course influences the prediction of all possible concepts as well as the life of the component in real service in the same degree.

The amplitude transformation resulted in unsafe predictions, because the used nominal S-N-curve is unsafe. The advantages of this concept should be kept in view.

It should once more be called to mind that these conclusions cannot be generalized, they are only valid for these flight-by-flight histories and this material. Finally some general remarks concerning the comparison of nominal and local approach:

The nominal approach needs for each k_t-value at least four S-N-curves. Service life curves can very quickly be predicted.

The local approach only needs one smooth specimen life curve. The cyclic stress-strain curve is a by-product. With these few input data, the local approach seems to perform the same as the nominal approach does with very numerous and thus expensive test results. With our program some thousands cycles per second can be calculated, so that computer time is no more a relevant problem.

We think that both approaches can be further developed. The number of improvement possibilities is much greater in the local approach, because this approach has direct regard to the mechanic and physical behaviour of the critical point in the component where failure occurs.

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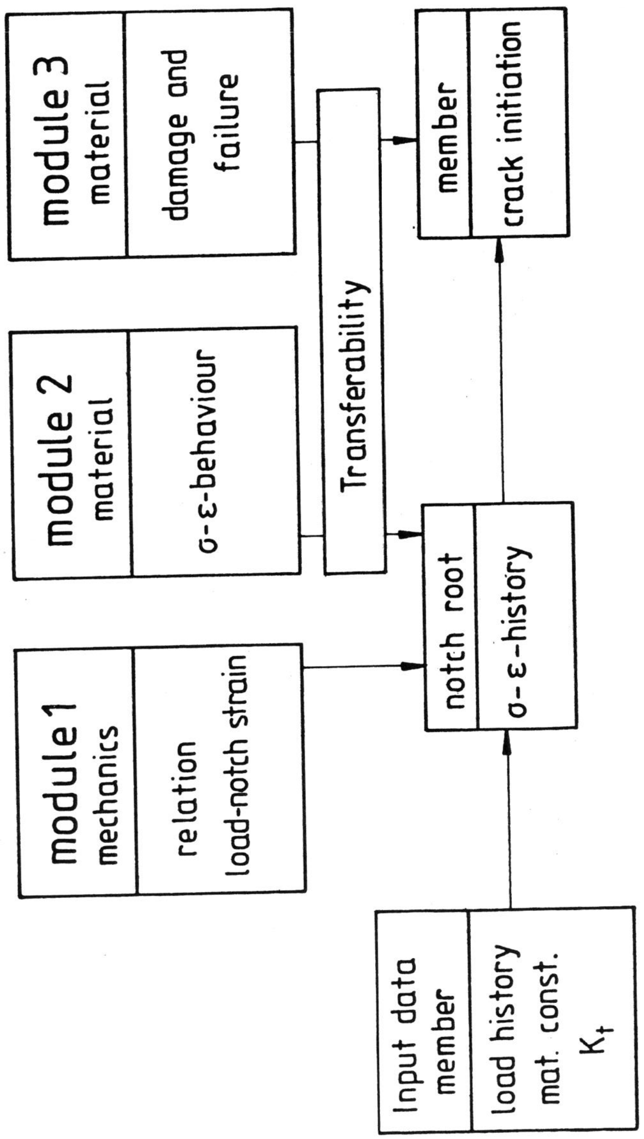

Fig. 1: Basic Scheme of the Local Approach

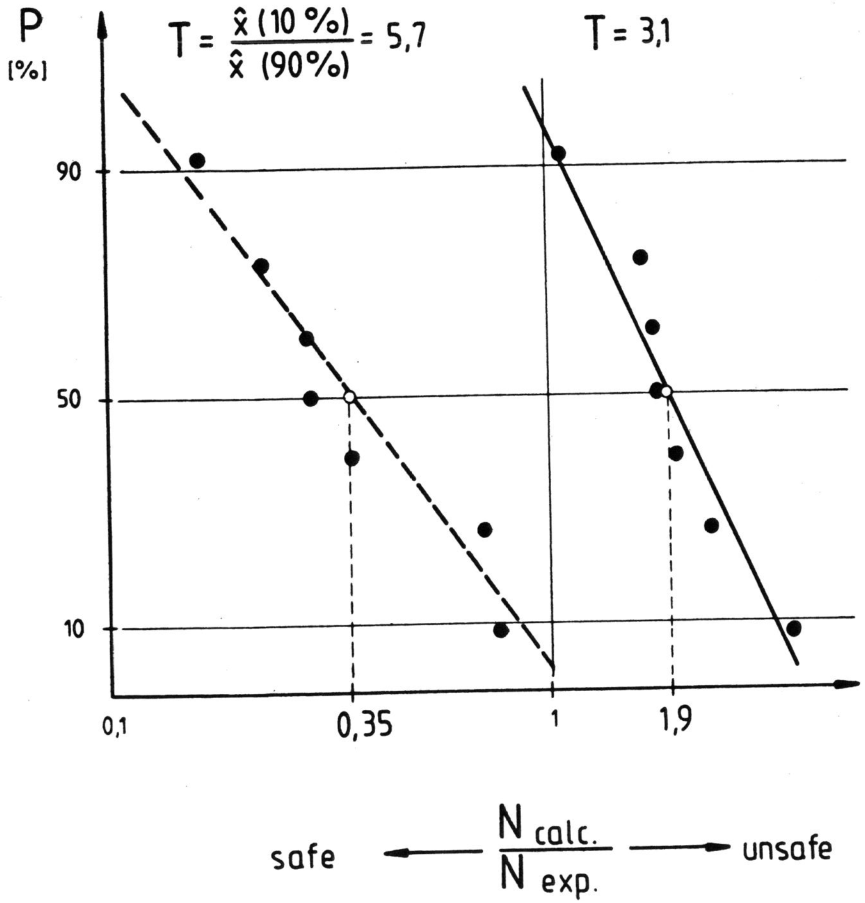

Fig. 2: Predictions with the Local and the Nominal Approach

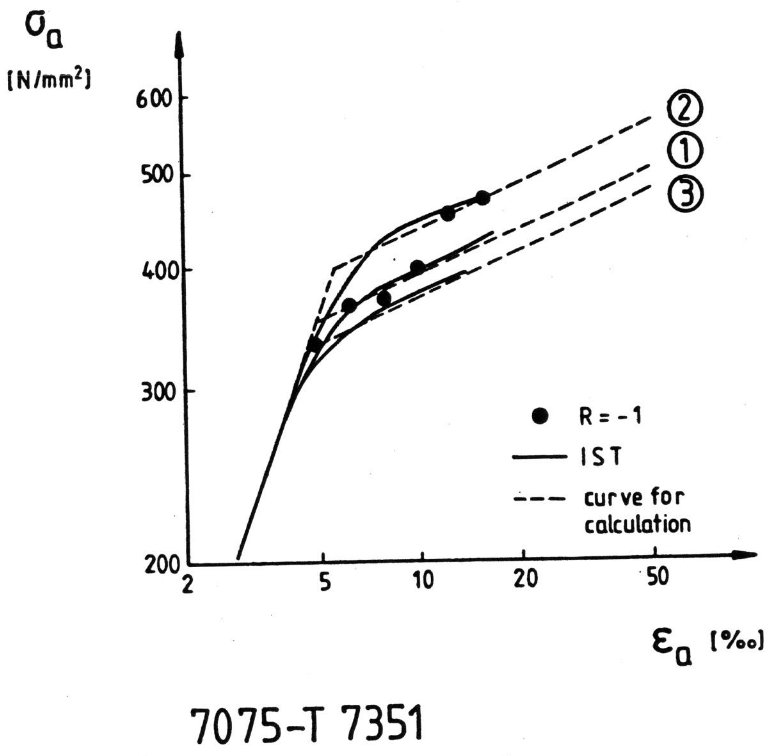

Fig. 3: Cyclic Stress-Strain Data 7075-T 7351

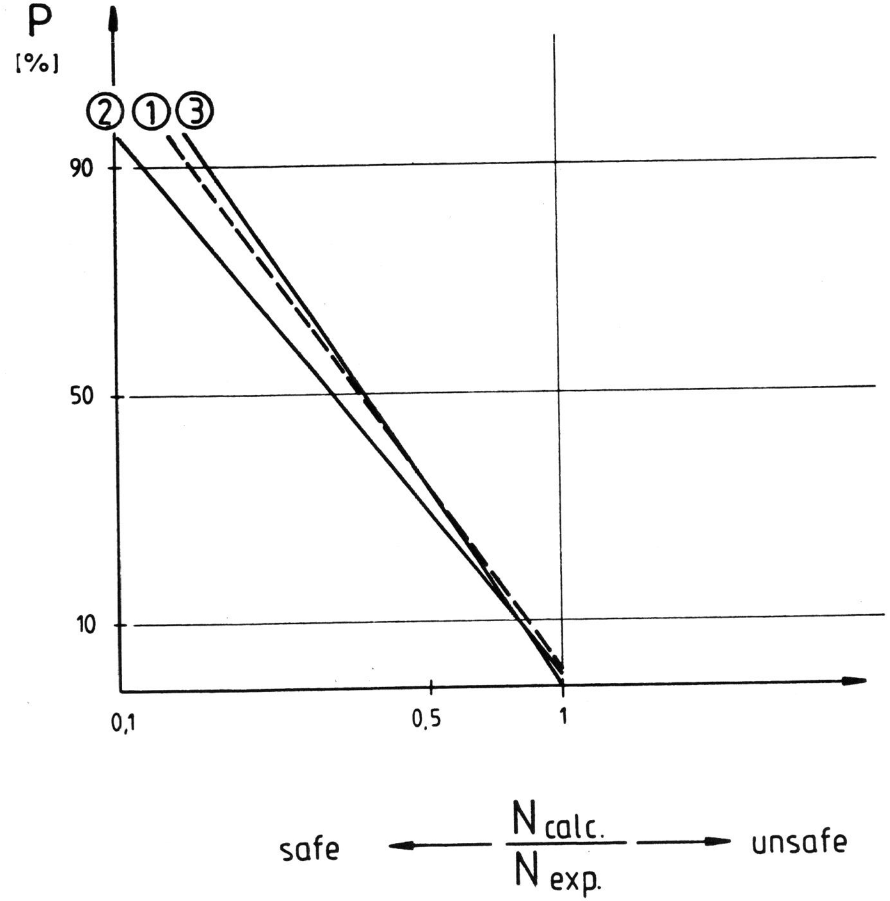

Fig. 4: Predictions with Different Stress-Strain Curves 7075-T7351

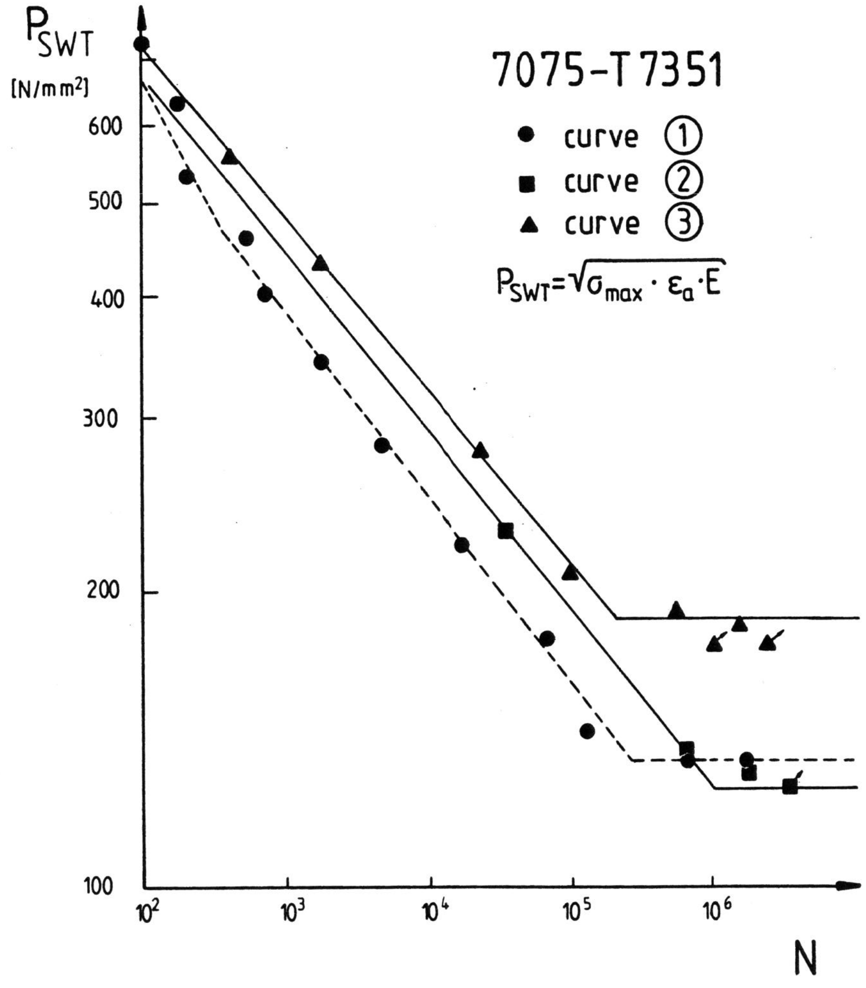

Fig. 5: Damage Parameter - Life - Curves for three samples of 7075-T7351

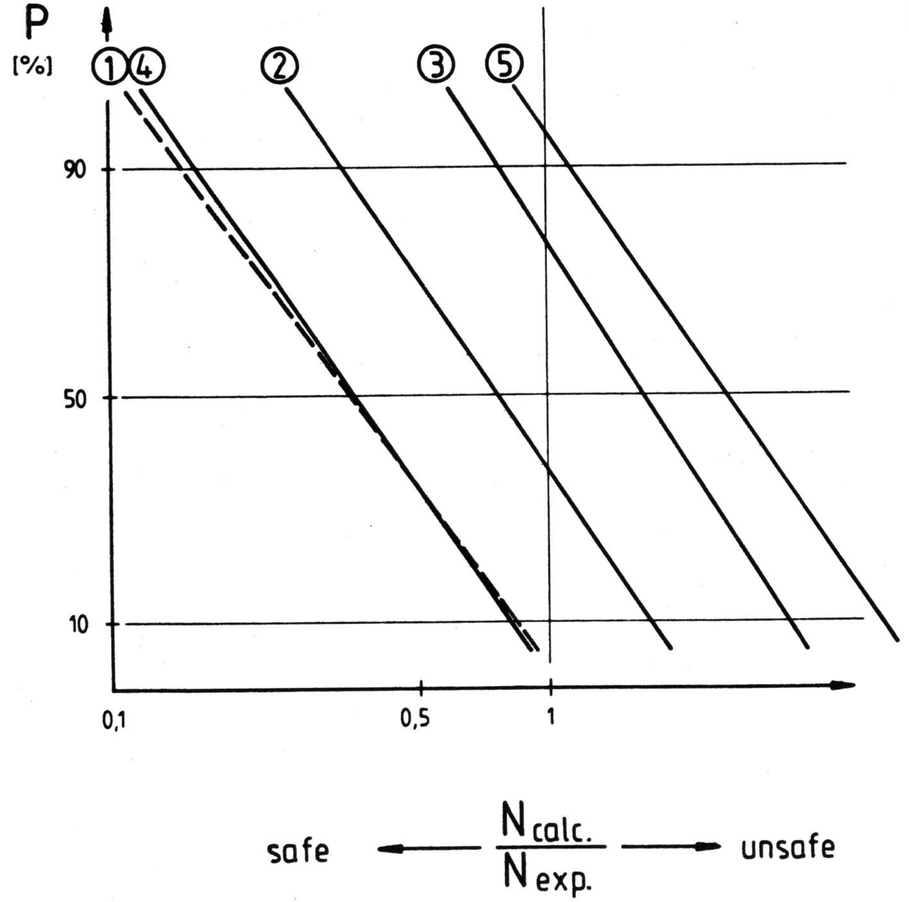

Fig. 6: Predictions with Different Damage Parameter - Life-Curves and Different Damage Parameters, 7075-T7351

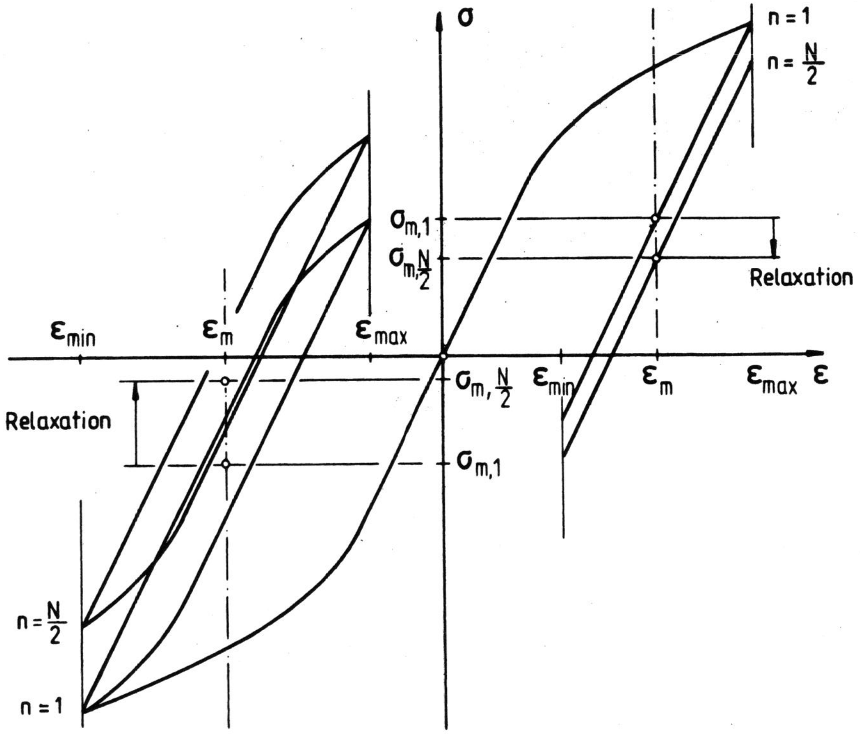

Fig. 7: Strain Controlled Tests with Constant Mean Strain

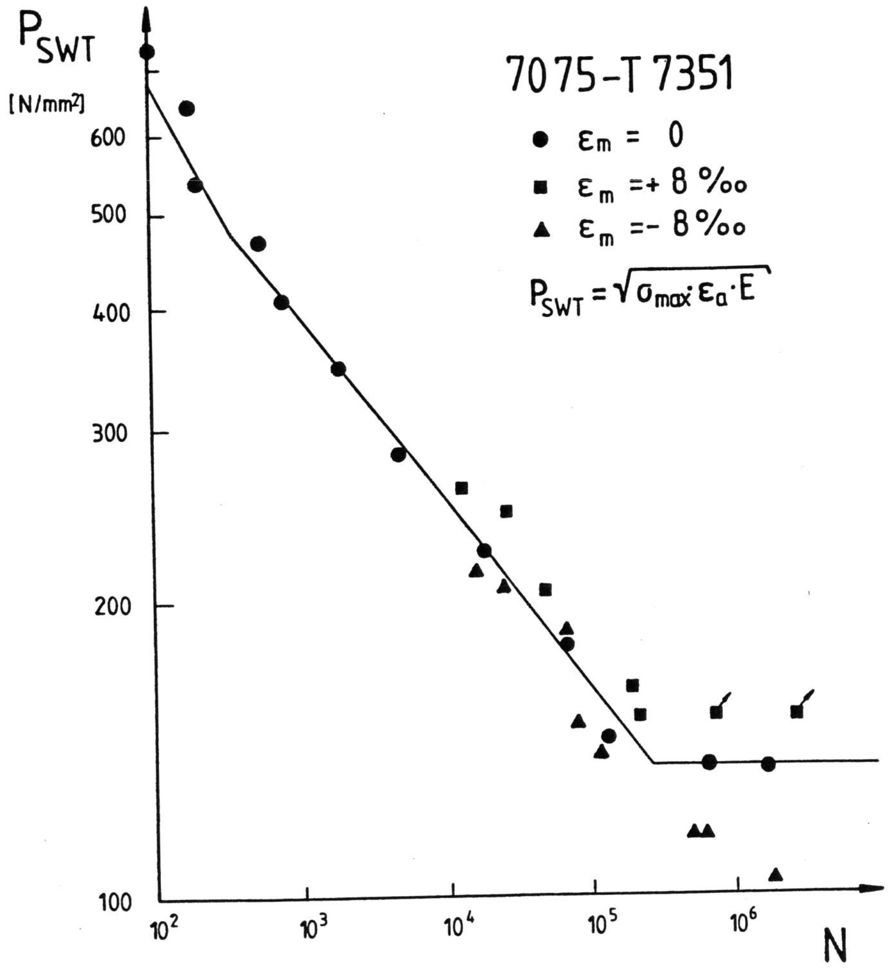

Fig. 8 Accuracy of the Damage Parameter after Smith, Watson, Topper

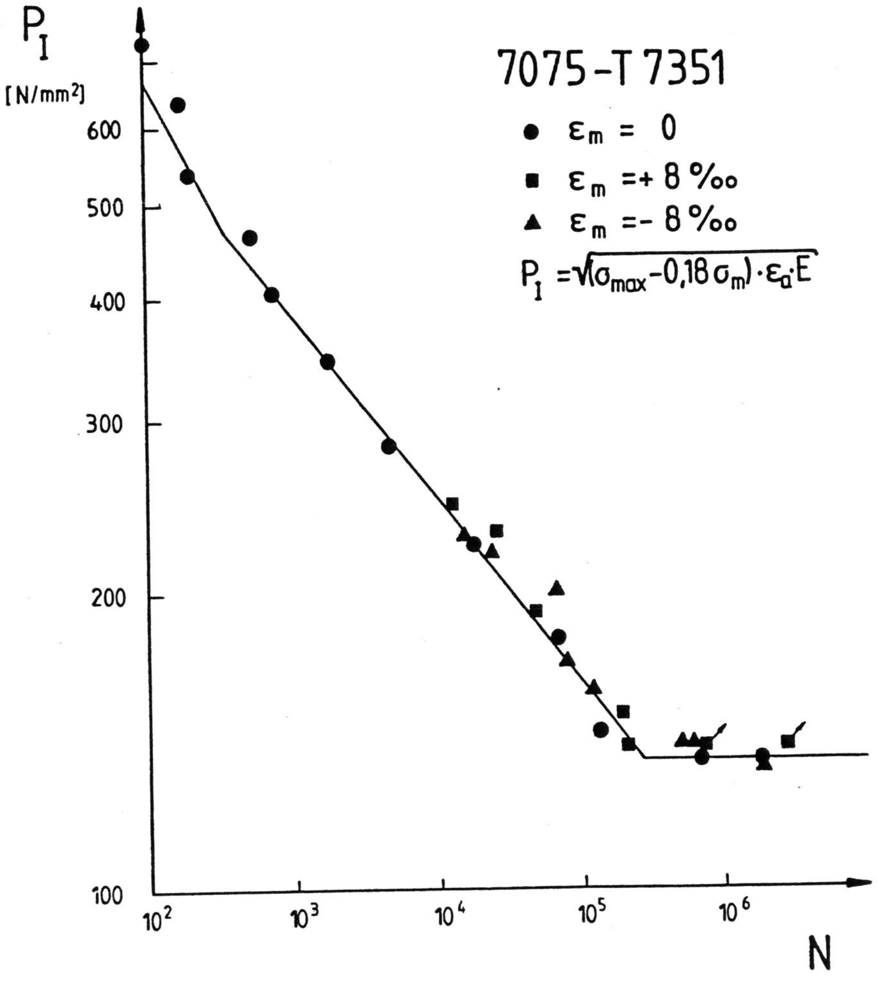

Fig. 9: Individual Damage Parameter P_I