Square and Slant Crack Growth in (Thin) Sheets

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ABSTRACT. *A fatigue crack normally grows in so-called mode I, with a flat fracture surface perpendicular to the loading direction. This can also be directed as square crack growth. Sometimes the crack front becomes slanted, at about 45° with the loading direction. In that case it is possible that the original crack growth direction is maintained, but also a deviated growth direction can be found. The paper describes various effects related to the occurrence of slant growth due to shear lips on fatigue fracture surfaces in (thin) sheets. After a general introduction the attention is focused on the relations between shear lips and fatigue crack growth. Questions about why shear lips develop and about other aspects of shear lip behavior will be answered. Several interaction effects combining shear lip behavior and fatigue crack growth rate are summarized, including the effects of frequency and environment.*

INTRODUCTION

In fracture mechanics it is simply assumed that cracks are perfectly flat and growing in the so-called mode I, i.e. in a plane perpendicular to the direction of the main principal stress. This is not always true. A slowly growing fatigue crack in a plate is largely growing in the "tensile mode", but at both surfaces of the material "shear lips" are frequently observed, see Fig. 1. Shear lips imply that the fatigue crack growth occurs in a mixed mode (I+III). Shear lips frequently are associated with a plane stress situation at the surface. As will be shown in the present study, the shear lip width is not a single function of the cyclic stress intensity. It also depends on how fast a crack is growing.

A lot of different types of experiments have been performed in order to find the behavior of shear lips and its influence on fatigue crack growth. Following Ref. [1] throughout this paper the shear lip width t_s was chosen as a characterizing parameter for the influence of the slant growth. The shear lip width is defined as (Fig. 2):

$$t_s = (t - t_t) / 2 \qquad (1)$$

In Ref. [2] the shear lip width of broken specimens was measured as a function of crack length. Specimens were sacrificed by grinding successive cross sections perpendicular to the crack growth direction (see Fig. 2).

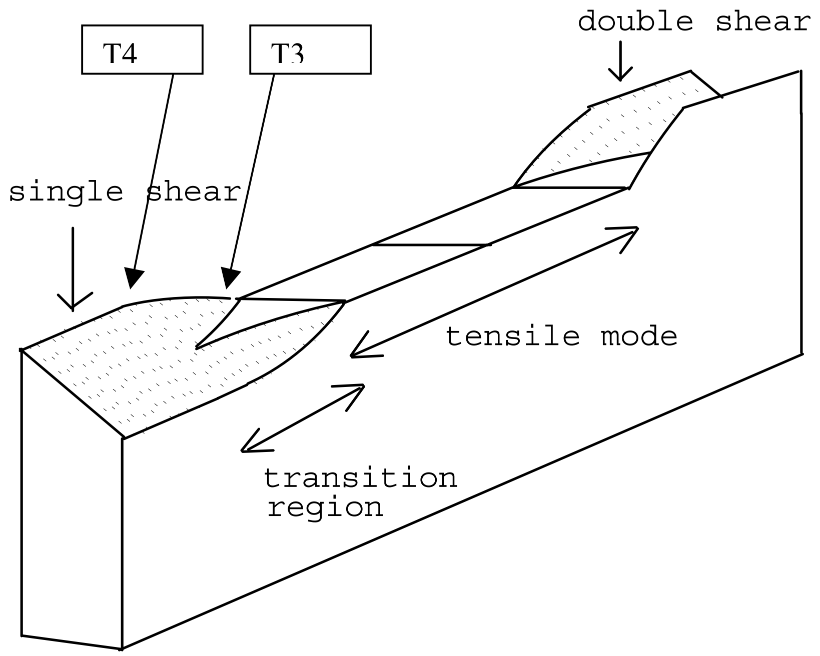


Figure 1. Drawing of the development of shear lips in a constant load amplitude test. At T3 the shear lips start, at T4 the surface is complete slanted.

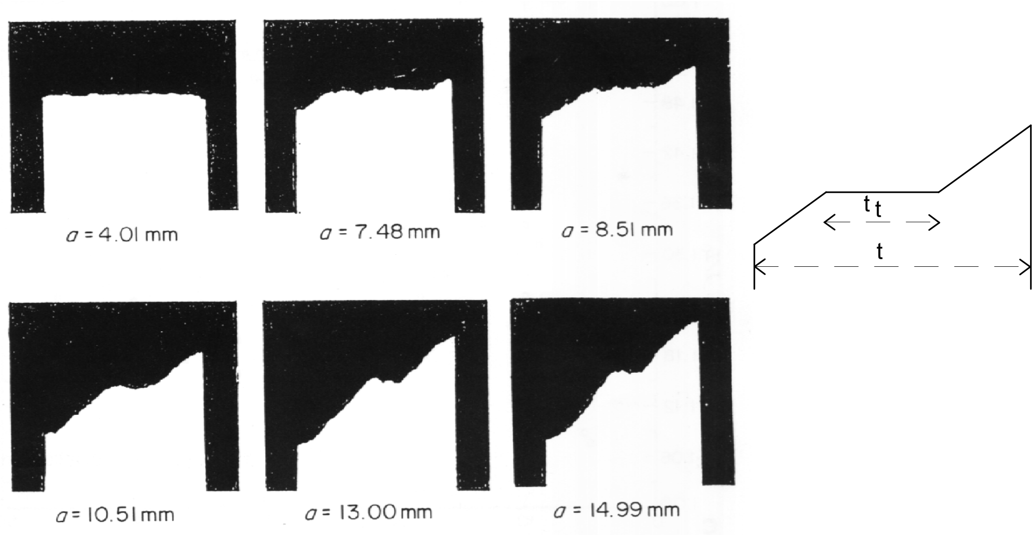


Figure 2. Transverse sections at increasing crack lengths.

In the case of fatigue crack growth it is often found that besides ΔK the crack growth rate also depends, to a lesser extent, on the frequency, the loading cycle shape, the temperature, the mean stress, and in general the load history during crack growth. If these conditions are not satisfied, a similitude between laboratory experiment and a real situation can be adopted only if these variables do not affect the crack extension mechanism. One important aspect is easily recognized. A crack with shear lips or a fully slant crack does not have the same crack tip geometry as a flat pure mode I crack.

TRANSITIONS IN FATIGUE CRACK GROWTH

A major development in the description of fatigue crack growth was the invention that the fracture mechanics parameter K could be used as controlling parameter. The description resulted in the well-known Paris power relation. Over a large crack growth rate area it was possible to relate the fatigue crack growth rate da/dN and the driving stress intensity ΔK linearly on log-log scale. However some slope changes occur in the part of the crack growth rate figure that is supposed to be linear, see Fig. 3. The transitions T1-T5 indicate slope changes, which probably can be associated with changes in crack growth mechanism. In this work we will confine ourselves to the transitions labeled T3 and T4. The transition T3 can be roughly associated with the start of shear lip growth and the transition T4 with the completion of it, i.e. the whole thickness has become slanted, compare Figs 1 and 3.

The transition to slant crack growth originates in the development of shear lips, which increase in width until they reach a material dependent maximum size [3]. In sufficiently thin specimens the shear lips meet at mid-thickness, which completes the transition to full slant crack growth. In (static) fracture testing the transition from the tensile mode to the shear mode is reasonably predictable; as it is related to the relative dimensions of the monotonic crack tip plastic zone and the plate thickness [4]. Under cyclic loading the process appears to be more complicated [5]. The transition usually starts when a critical value of da/dN or ΔK_{eff} for a given material and thickness is exceeded [6,7,8,9,10]. Investigations on AA 2024 T3 and AA 7075 T6 have shown that the change in fracture mode starts at a critical rate of growth of the order of 0.1 μm/cycle. The completion of the transition occurs at higher values (about 1 μm/cycle) [1,11,12], depending on the material thickness [9,13]. The same trend can be observed in Fig. 3. The transition could be reversed by reducing the cyclic load level [14,15].

A statement that can be made with reasonable confidence is that the attainment of a critical value of ΔK_{eff} (or da/dN) is a necessary condition for the appearance of shear lips. It is also assumed that a state of plane stress is a necessary condition for shear lip growth and completion of the transition. No single condition, plane stress or da/dN, is by itself sufficient [16]. The mechanisms responsible for the transition to slant growth in thin sheets are not clear, although the actual crack growth mechanisms (by striations) are the same as in mode I fatigue crack growth [16,17,18].

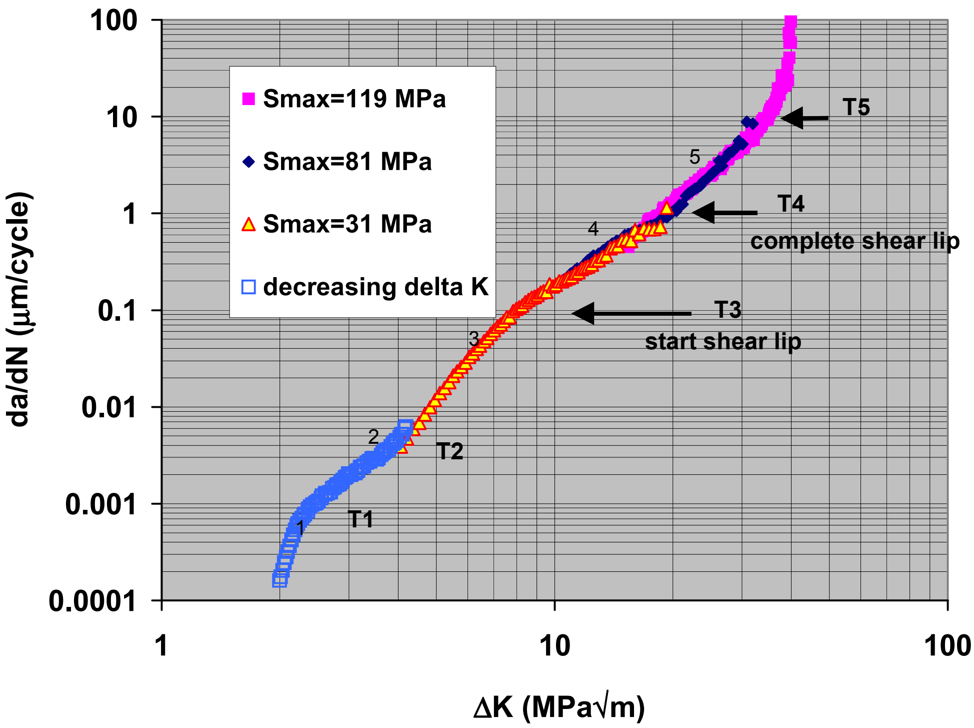


Figure 3. Experimental fatigue crack growth rate results for AA 5083 R=0.1, f=10 Hz, specimen thickness 8 mm.

An argument against the association of shear lips with a plane stress situation is the observation that higher R-values promote tensile mode crack growth [19]. The authors also observed this trend. They found that the start of shear lips is not dependent on K_{max}, whereas normally the plane stress situation is assumed to depend on K_{max}. A large difference in K_{max} values was applied, ranging from about 10 to 50 MPa√m, at the same constant ΔK_{eff} =5 MPa√m. In all cases no shear lips were found. This rules out the plane stress plastic zone size as a controlling parameter.

Shear lips are sometimes thought to result from general out-of-plane sliding which allows an antiplane strain (K_{III}) mode of fracture to operate. This seems to occur easily in thin sheet (tensile) specimens, because of elastic crack edge buckling (out-of-plane displacements), which develop into concentrated shear on 45 ° planes [17]. However, the fact that shear lips are also present in thick specimens rules out buckling as a major cause. In Ref. [16] it is stated that a possible explanation of the transition is that the development of shear lips is an instability effect.

Forman et al. [6] also observed an effect of the fracture mode on da/dN. They suggested that two independent eq.'s of the same basic form (power law) were needed to describe the da/dN - ΔK behavior, one covering flat fracture, and a second one for shear mode cracking. The same can be observed in Fig. 3. In the crack growth rate area between T3 and T4 the slope is lower than that before T3 and after T4.

One of the present authors and his co-workers [20] introduced the constant ΔK test to study shear lip behavior and crack growth rate during growth of shear lips. This type of experiment is a good test to get reliable quantitative information on both shear lip width and associated da/dN behavior. It was noted that in the beginning of the constant ΔK test, when the crack surface was still flat, the crack growth rate was much higher than later on, when shear lips did develop at growing crack length. A decrease of about a factor 3 in da/dN was found for crack growth in AA 2024 going from a tensile situation to a situation of complete shear [2]. The unstable crack growth rate at the start of the constant ΔK test was called tensile mode crack growth rate. The decrease in crack growth rate was later confirmed by Ling and Schijve [21]. They found a decrease with a factor 3 to 4, from measurements of striation width. They also performed constant ΔK tests.

EQUILIBRIUM SHEAR LIP WIDTH

The shear lip width t_s as a function of the crack length was measured in a large number of tests, performed at constant ΔK and first at a frequency of 10 Hz [2]. Later on other frequencies were used [22]. A result of the tests is shown in Fig. 4. Based on the observations two assumptions were made. First it was assumed that for a constant ΔK and R test the shear lip width t_s tend to reach an equilibrium value $t_{s,eq}$. It can take a considerable amount of crack growth before this equilibrium situation is reached. Further the material must be thick enough to physically reach $t_{s,eq}$. Secondly it is assumed that the rate of widening of the shear lips is governed by the difference of $t_{s,eq}$ and t_s. The widening rate decreases when the shear lip width t_s grows. Mathematically such assumptions lead to:

$$t_s - t_{s,o} = (t_{s,eq} - t_{s,o})(1-e^{-c(a-a_o)}) \qquad (2)$$

a_o and $t_{s,o}$ are initial crack length and shear lip width. For an initial shear lip free flat fracture surface $t_{s,o}$=0. Values of $t_{s,eq}$ and c were determined by the best fit of eq. 2 through the data points, using a least squares method. Results of the fitting procedure are shown as the solid lines through the data points in Fig. 4. The regression analysis can lead to problems if the shear lips grow to a width of t/2 (full slant mode). A larger shear lip width is physically impossible. In such cases t_s - a data, where $t_s \approx t/2$, were omitted, because otherwise a good fit was not obtained. It had to be assumed that $t_{s,eq}$, as result of the regression analysis, could theoretically be higher than half the plate thickness t/2. The larger shear lip width could actually be obtained only in a thicker specimen. Recently it was found that shear lips could also be suppressed on one side, making it possible to find $t_{s,eq}$ also in thinner plates [23]. It was shown that eq. 2 could also be used to predict shear lip shrinkage, see Fig. 4.

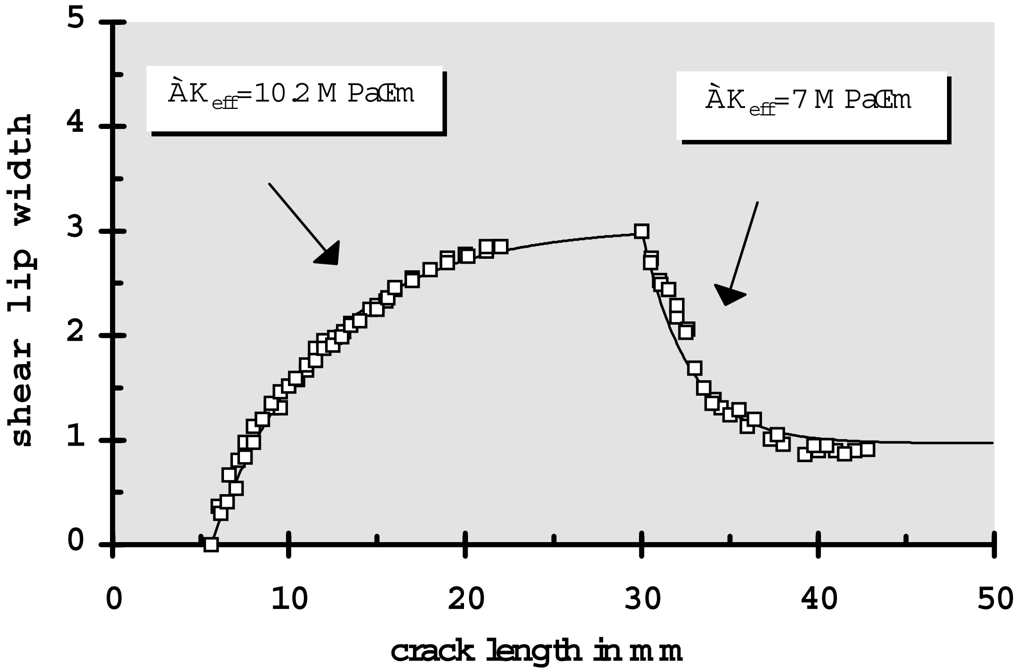


Figure 4. Shear lip width growth and shear lip width shrinkage.
6.0 mm plate thickness; K_{max} =20.6 MPa√m ; R=0.05 until 30 mm, then 0.52

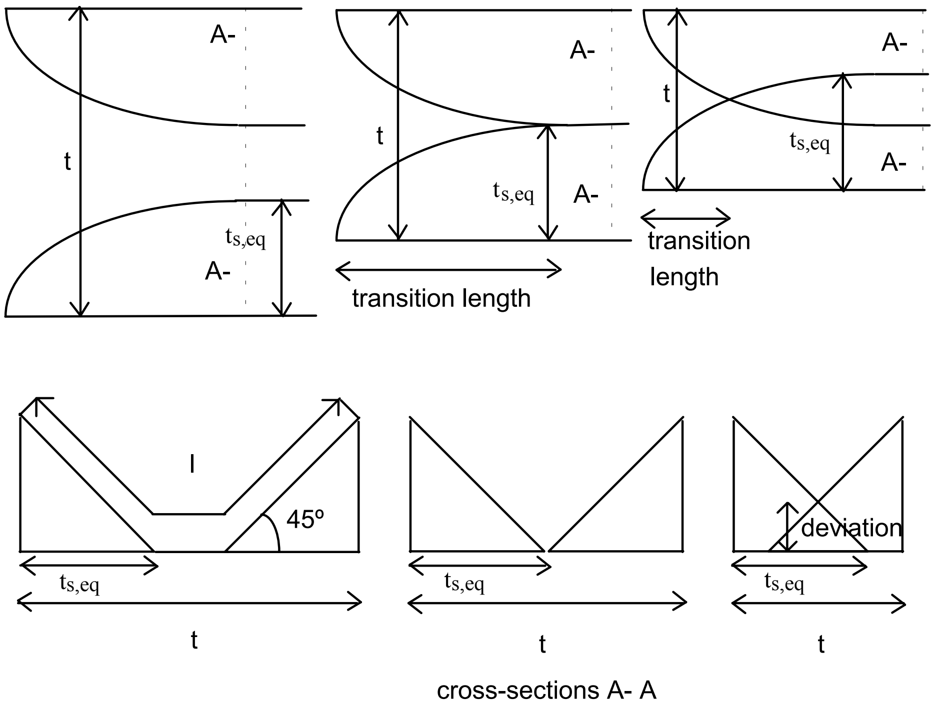
In order to explore whether the value $t_{s,eq}$ of all tests could be related to fracture mechanics parameters, these value was plotted against K_{max}, ΔK and ΔK_{eff} . There was a poor correlation with K_{max} and ΔK, whereas the correlation with ΔK_{eff} was surprisingly good. Regression for $t_{s,eq}$ led to eq.3:

$$t_{s,eq} = 0.67\ \Delta K_{eff} + 0.64\ \log(f) - 4.35\ \text{(mm)} \qquad (3)$$

where $t_{s,eq}$ is given in mm, f in sec^{-1} and ΔK_{eff} in MPa√m. Eq. 3 is based on two thicknesses, 6 and 10.3 mm. A thickness effect was not observed. The effect of the frequency f was also introduced by making a three parameter fit on all results. The results suggest a unique relation between shear lip width and crack growth rate. It was concluded that the same da/dN (in a stationary situation) will always be accompanied by the same $t_{s,eq}$ and vice versa. Both are a measure for each other.

INTERACTION OF SHEAR LIP WIDTH AND THICKNESS

The results suggest that $t_{s,eq}$ is not dependent on the specimen thickness, but only on ΔK_{eff}. It will be assumed that this thickness independence has a general validity. The consequence is illustrated by Fig. 5. The same $t_{s,eq}$ value is used for three plate thicknesses. Only in thicker plates can $t_{s,eq}$ be measured directly on the fracture surface. The fact that $t_{s,eq}$ is only dependent on ΔK_{eff} and not on the plate thickness is important for the transition length at completion, i.e. at T4. It will be clear from Fig. 5 that the transition length is larger for a thicker sheet. For $t_{s,eq} < t/2$ there is no such transition length. The independence of $t_{s,eq}$ on the plate thickness, which leads to a longer transition length in thicker plates, is also experimentally confirmed by Refs [24] and [25].



a) $2t_{s,eq} < t$ b) $2t_{s,eq} = t$ c) $2t_{s,eq} > t$

Figure 5. Double shear lip width development in a constant ΔK_{eff} test. the transition length is longer for a thicker specimen

The transition can also lead to thickness dependence in fatigue crack growth behavior [26]. Indications were obtained that the effect of sheet thickness on da/dN mainly occurs in the transitional area, i.e. T3-T4 [24,25]. No thickness effect on da/dN is found for cracks in the tensile mode [27]. No thickness dependence was found for the shear lip width. It depended only on ΔK_{eff} [28]. For double shear lips the transition in thinner specimens often leads to deviated crack growth. The principle is shown in Fig. 5c. This was not observed for single shear lips.

EFFECTS OF FREQUENCY AND ENVIRONMENT

The transition from a tensile mode to a shear mode fracture in AA 2024 and AA 7075 was found to depend on the environment. A more aggressive environment shifts the transitions T3 and T4 to higher values of ΔK [29,30]. Similar indications are reported for steels in air and seawater. In seawater no transition was observed for the ΔK range, which produced fracture mode transition in air [31]. At least part of the environmental or frequency influence on da/dN in Al alloys can be associated with the presence of shear lips. Before the transition is completed, different values of the crack growth rate in dry and wet air are found, while above this point there is no effect left [32]. The same effect has been found for crack growth in Titanium in air and salt water [33]. The environment also has influence on the fracture surface appearance. It was found that a flat fracture surface was promoted by an aggressive environment or by a low frequency in air. Higher da/dN is needed to find shear lips in a more aggressive environment. Also the shear lip appearance is dependent on the frequency in air. Smooth regular shear lips were found for low frequencies, while very rough shear lips were found at higher frequencies in air. For tests performed in vacuum almost directly rough shear lips were formed at all ΔK‘s. It was also found that rough shear lips had an enhancing effect on crack closure and that smooth shear lips had no effect [15,28]. This was found by removing the crack flank material until 1 mm from the crack tip. Then the effect of this operation on da/dN was measured. A jump in da/dN resulted for rough shear lips.

PRACTICAL RELEVANCE

The width of shear lips and their growth would only be of scientific interest if there were no effects on the crack growth rate. Some authors found higher crack growth rates due to shear lips [34,16,35,36], while others found just the reverse with a decrease in da/dN by a factor of 2 to 3 [9,18,37,38,39]. The authors, who found higher growth rates due to shear lips, did so on the basis of different slopes of the log (da/dN)-log (ΔK) lines below and above the (end) transition point T4 (see Fig. 3). After the transition had ended the slope was found to be higher than before. From this it was concluded that shear lips enhance the crack growth rate. In Fig. 3 it is shown that the slope in the transitional area, between T3 and T4, is lower than beyond the end transition point T4. However, this fact does not mean that shear lips have an accelerating effect on da/dN, but rather that they have a retarding effect on da/dN in the transitional area, i.e. the area where shear lips grow.

The significance of the transition from an engineering point of view is twofold [40]. First, as was already mentioned, it might cause a change of the slope in the log (da/dN) - log (ΔK) relationship [6,26,38,39]. Secondly, if shear lips are present, the R ratio sensitivity under constant amplitude conditions increases. Under variable amplitude loading the effect of the load sequence will be much more important when shear lips are present, because the effect of crack closure is much larger when shear mode growth occurs [41,42,43]. Although shear mode crack growth is often observed in laboratory specimens, this behavior is rarely observed in cracks in general engineering structures. This means that the load sequence under random loading is less important than might be supposed from the results of laboratory tests involving isolated overloads. However historically the majority of crack growth rate data have been generated under constant amplitude conditions. Because of the simplicity of the tests it is expected that this will not change in the future. Therefore the need remains for a method capable of predicting crack growth in different geometries using data generated in a constant amplitude test.

CRACK DRIVING FORCE AND CRACK GROWTH RESISTANCE

In order to find the effect of shear lips on the stress intensity factor K, three dimensional finite element calculations [44,45] were performed on the stress intensity distribution in center-cracked plates. A decrease of about 40% in K_I was found when a complete single shear situation is compared with a tensile situation. Even so, a translation of this result to fatigue crack growth is difficult. We not only have to consider crack growth driving force, but also resistance and often also crack closure as extra complicating factors.

Let us assume that when a shear lip is formed (regular or irregular) there is a decrease in K_I of 40%, as indicated by finite element calculations. Let us also assume that mode II and mode III crack growth can be neglected in comparison with mode I growth in the situation of a growing crack in a center-cracked tension specimen under uniaxial tensile loading conditions. For smooth shear lips (obtained at low frequencies) no decrease in da/dN, in a constant ΔK test with growing shear lips, is found despite the calculated reduction in K. For smooth shear lips also little or no (extra) closure is found. These facts point to the conclusion that the effect of shear lips on crack growth resistance must cancel the effect of shear lips on K.

This conclusion is supported by some reasonable physical arguments. The crack growth resistance is mainly due to the energy involved in plastic deformation at the crack tip. The plastic zone size depends on K. Then it seems reasonable to expect that if there is a decrease in K, thus a lower driving force, there will also be a smaller plastic zone, leading to a lower crack growth resistance. Thus the lower driving force will be partly compensated for by a lower crack growth resistance in the case of smooth shear lips. Of course this explanation is very rough. For rough shear lips, at higher frequencies, the same argument with respect to driving force and crack growth resistance can be adopted. The only difference now is that a significant crack closure is present. This roughness induced closure is responsible for the observed decrease in da/dN at growing shear lips and for retardation in da/dN after underloads [28].

An alternative explanation on the difference in behavior of smooth and rough shear lips can be given based on a contribution of K_{III} to crack growth. Finite element calculations predict both a decrease in K for mode I of 40 % and an increase in K for mode III to 40% of the original mode I K value. If mode III crack growth is not neglected in the case of shear lips, then smooth shear lips are expected to lead to higher crack growth rates than rough shear lips do. The reason is the much higher mode III crack closure in the case of rough shear lips. It seems reasonable to expect that in the combined mode I plus mode III crack growth the mode III crack growth rate is higher than in pure mode III, because the tensile loading that opens the crack in mode I reduces the mode III crack closure. For smooth shear lips this opening of the crack is possibly just enough to find a da/dN that is about equal to da/dN resulting from mode I loading at the same ΔK. For rough shear lips the mode III closure may be too high to be overcome by the mode I opening.

SOME PHYSICAL EXPLANATIONS OF SHEAR LIP BEHAVIOR

Based on the observed facts a few questions are formulated and answered [28].

Why do shear lips develop

The reason why shear lips develop in some materials and not in other materials probably has its origin in the material structure and the type and amount of texture. It is well known that the stress situation near a through crack on the plate surface is plane stress [46]. Therefore a simple mechanical explanation is that the process is induced by a situation of plane stress at the specimen surface, which leads to maximum shear stresses on planes inclined at 45° to the specimen surface. A situation of plane stress is considered a necessary condition for the initiation and growth of shear lips, necessary but not sufficient. Materials with face centered cubic or body centered cubic structures have many possible slip systems. There will always be a slip possibility near the direction of maximum shear stress (except in a theoretically extreme texture case). Shear lips will form easily in these materials. An exception was found for austenitic stainless steel, a material with a face centered cubic structure, where no shear lips were found in tensile and fatigue tests [22]. The reason probably is a martensitic transformation in this material near the crack tip. The tetragonal structure of the martensite probably has no easy slip systems near the directions of maximum shear stress. For hexagonal closed packed materials the situation is analogous because there are only three slip systems composed of three closed packed directions <1000> and the closest packed {0001} planes. Quite often the texture in plate geometries of hexagonal materials is such that {0001} is parallel to the plate surface. There is thus no easy slip system near the maximum shear stress direction. Shear lips are not detected for these materials. The conclusion is that shear lips will form always unless there is a hindrance of the necessary slip under 45° with the plate surface.

Why shear lip start depends on ΔK_{eff} and not on K_{max}

It was found that the equilibrium shear lip width and the start of it depended on ΔK_{eff} (eq. 4), and not on K_{max}. At higher K_{max} there is more plane stress. Why thus should the shear lip width be dependent on the fatigue crack driving force ΔK_{eff} and not on K_{max}? An answer to that question might be found using a time dependent description of the fatigue crack growth process with growing shear lips. It is assumed that the initiation of shear lips needs some crack growth. In fatigue (in the Paris regime) we have some crack growth in every cycle. It is generally thought that crack extension is not a continuous process during one cycle. There is only crack growth during the increasing part of K. The crack growth rate increases with K during this process. Somewhere near the maximum value of K the crack growth rate will start to decrease and is assumed to become zero when K is decreasing. The process of crack growth during the increasing part of the K cycle and no crack growth and resharpening of the blunted crack during the decreasing part is repeated for the next cycles. Suppose that we have a tensile mode situation of crack growth in a constant ΔK test. In every cycle we have the same (discontinuous) crack length increment. When will shear lips develop? It may be clear that the shear lip growth has to occur (start) during this small period of crack increment in one cycle, thus during the increasing K period. If the crack length increment in one cycle is too low for the initiation of shear lips, this will also be the case in the next cycles. Apparently there is no "history" effect for shear lip initiation as long as the crack surface is in the tensile mode. The reason for this is that in every cycle the crack grows a certain amount, making a new fresh (sharpened) crack tip area for the shear lip to try to initiate in the next cycle. Moreover, initial dislocation movements, needed for the start of shear lip growth, are (partly) reversed during the unloading K period of the fatigue cycle. Thus we need a certain continuous crack length increment (which is equivalent to a certain da/dN or ΔK_{eff}) to initiate a shear lip. Below this value initiation of shear lips will not occur even after a large number of cycles. This is in agreement with eq. 4. When at a higher ΔK the crack increment is sufficient for initiation of shear lips in a cycle, then it will also be sufficient in the following cycles.

From this model we learn that we need a certain amount of crack growth in a cycle (i.e. da/dN) to get shear lips. Therefore the initiation of shear lips depends on ΔK_{eff} and not on K_{max} , because da/dN does not depend on K_{max} .

Why is there an effect of frequency and/or environment on the start of shear lips

For materials that form shear lips a dependence of the forming of shear lips on the frequency (environment) was found. When the loading frequency is lowered (or the environment is made more agressive, e.g. by change from from air to salt water), it was found for AA 2024 that start of shear lip width development is shifted to higher values of ΔK or da/dN, and flat tensile mode crack growth is favored. What can be the explanation for this phenomenon? Remembering the foregoing discussion about the necessity of a slip possibility in the directions of maximum shear stress a possible explanation can be that the more aggressive environment has an impeding effect on (the start of) dislocation movement along the slip systems near the plate surface.

There are two possible causes for the impeding effect. First the effect can be thought to result from foreign atoms or ions, products of a corrosion reaction near the surface, diffusing into the matrix. They settle near dislocation lines where the lattice spacing is higher than elsewhere. The settlement of foreign elements (substitutional or interstitional) near the dislocation lines has a lowering effect on the total internal energy, i.e. it costs energy to move the dislocation lines out of this environment. The (start of the) movement of dislocation lines has become more difficult. Another possibility might be that dislocation lines near the crack tip surface are pinned by the oxide layer on the surface, for example they lay slant through the oxide layer surface [47]. This oxide layer will have more "pinning" effect when the frequency is lower, because the oxide layer will have more time to grow. There probably has to be a little initial slant growth at the surface, before shear lips can grow to a larger width. If this initial shear lip growth is prevented by hindrance of dislocation movements near the surface shear lips will only start to grow at higher ΔK . Thus da/dN at the start of shear lips is higher and herewith also ΔK_{eff} . The shear lip development will be later and less.

In vacuum shear lips develop almost immediately when the crack grows, even for a very low ΔK_{eff} and for a low frequency. There are no obstacles for dislocation movements needed for the start of the shear lip growth.

Why there is an equilibrium value $t_{s,eq}$ at a constant ΔK test

For higher values of ΔK_{eff} the crack growth increment per cycle is large enough to start shear lip growth. When in a cycle a shear lip is initiated, the stress situation (initiation of mode III stresses) at the tip has changed. Every cycle adds a small shear lip increment to the already present shear lip width. It was shown that growing shear lips can be associated with a decrease in da/dN. Suppose that we start fatigue crack growth from a tensile mode prefatigue crack at a high constant ΔK. Already in the first cycle the shear lip growth starts. Then in the next cycle there is an initial shear lip width (very small), which can be associated with a lower da/dN than in the first cycle. The lower da/dN in the second cycle leads to a lower increase of shear lip width (dt_s) than in the first cycle. In the next cycles, in every single cycle the increase of shear lip width and the decrease in crack growth rate are smaller than in the previous cycle. This process is going on until the changes (per cycle) in t_s and da/dN are very small (about zero), the equilibrium values $t_{s,eq}$ and $(da/dN)_{eq}$ are now reached. The value of $(da/dN)_{eq}$ depends on $t_{s,eq}$ and reverse (compare eq. 4).

RECENT DEVELOPMENTS IN UNDERSTANDING SHEAR LIP BEHAVIOR

Very recently it was found that shear lips on AA 5083 could be suppressed by making a small scratch along the crack growth direction [23]. A scratch depth of 0.1 mm was enough to avoid effects on the crack growth rate. The specimen thickness was 8 mm. The shear lips in this material showed a smooth appearance. A remarkable effect was found. Specimens with shear lips and without shear lips showed the same da/dN-ΔK result when loaded identically in constant amplitude. Also the same transitions T3 and T4 were present. Thus the shear lips could not be responsible for the slope change after T3. It had to be accepted that another mechanism was responsible for both development of shear lips and the slope change in log(da/dN)-log(ΔK). The same technique was also performed on AA 2024. Here the suppression by the scratches was not sufficient, i.e. the (rough) shear lip did break out the scratch with a result on da/dN.

At this moment a corrosion mechanism is held responsible for the shear lip phenomenon and the associated crack growth rate behavior. It is thought that the corrosion mechanism gradually loses its influence by increasing da/dN from T3 to T4. This causes the slope change. At T4 no corrosion enhanced crack growth rate is left. The slope increases about to the value it had before T3. From here the growth rate is the same as in vacuum or dry air.

CONCLUSIONS

In the present paper various aspects of shear lips on fatigue fracture surfaces have been analyzed.

- Necessary conditions for shear lip development are 1) a plane stress situation, 2) a material structure with a slip possibility near 45° with the plate surface and 3) a da/dN that is large enough to permit shear lip initiation in the crack growth period within one cycle.
- The lower slope in log(da/dN)-log(ΔK) between T3 and T4 is caused by a corrosion enhanced crack growth mechanism that gradually loses effectiveness. Below T3 the corrosion mechanism is fully cooperative. Above T4 the enhanced mechanism does not longer exist.
- Smooth shear lips have no effect on da/dN. Effects of smooth shear lips on K and crack growth resistance cancel each other. Rough shear lips have a retarded effect on da/dN due to roughness induced crack closure.
- When a failed component shows a shear lip, the width of the shear lip is an indication for da/dN, or for the applied ΔK_{eff} or ΔK. From the shear lip width it is possible to get a global impression of da/dN, and from striation measurements we get a local da/dN. Fluctuations in shear lip width indicate loading transitions. Large shear lips point to a high ΔK_{eff} (high loading) and rough shear lips point to a high frequency.

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