DOWNLOAD PDF FATIGUE DAMAGE OF MATERIALS

Chapter 1 : Fatigue Damage of Materials: Experiment and Analysis

Fatigue damage becomes an important limit state for the design of structures because, most of the time, materials with high static strength are used in service and there is no simple correlation between the static strength and the fatigue strength.

Equation 6 is modified as follows: Since the stress ratio is constant during the modeling cycle, is a constant too. The modified model has less fitting parameters and is accommodative to be integrated into finite element programs. Combined with geometric equation, constitutive relation, equilibrium equation, and boundary conditions, the damage evolution model modified above can be applied to compute the lifetime based on known conditions of stress and damage. The lifetime estimation of damage initiation and propagation is accomplished by the damage mechanics-finite element method. Numerical Methods of Fatigue Life Prediction Damage mechanics-finite element method [10 , 13] is employed for the fatigue life prediction and damage field simulation. The main feature of the method is that the damage increment of dangerous point is kept constant in the analytical process. The steps could be described as follows: At the first loading step, the values of damage of the elements are assumed to be zero. Furthermore, the damage status of the dangerous point needs to be checked during every loading step, and if it has failed, the dangerous point of the structure should be reestimated. The value of total life is updated as 4 The damage increment of gauss points of other elements is obtained on the basis of life increment: The damage values of gauss integral points of each element are 5 With the new damage field, the stress field is updated until the components lose efficacy or is infinitesimally smaller than. The damage mechanics-finite element method is implemented in ABAQUS, coding with Python and Fortran to use the built-in functions, such as finite element modeling, postprocess of stress, and damage field analysis results. The implementation flow chart of damage mechanics-finite element method is shown in Figure 1. After that, the structural stress will be analyzed. Numerical scheme for damage mechanics-finite element method. Numerical Investigation The high-cycle fatigue life of standard test specimen of TC4 alloy is analyzed using finite element program with damage mechanics calculation method implemented in ABAQUS. The simulation results are validated through comparing them with the fatigue test results in Practical Handbook of Engineering Materials [14]. Then, the fatigue life of notched specimen is predicted according to the damage evolution model with parameters verified by experimental results of smooth specimens. Parameters and of damage propagation formula are obtained by fitting the damage evolution model through the fatigue test results of standard smooth test specimens of TC4 alloy in Practical Handbook of Engineering Materials [14]. For the smooth components: Combination of the test results of the standard smooth test pieces of TC4 alloy and closed-form solution method of fatigue life prediction [15], with the integral of 6 , is is derived according to the test results. The value of damage increment is required by damage mechanics-finite elements algorithm and determined appropriately to reduce the computing time [16]. The value of as 0. During the process of data fitting, parameter is found to be dependent on experimental data chosen largely. According to the general rules of metal damage evolution and symmetrical stress of cross section of smooth specimen, an assumption [17] is made that a high proportion of the component fatigue life corresponds to the first dangerous point failure life and then the other elements will lose efficacy rapidly after failure. Thus, according to 7 , with the fitting formula listed as parameter , after choosing a test life of a certain stress level. The value of nominal maximum stress of specimen section is MPa. Loading and boundary conditions of tensile-tensile fatigue standard samples in accordance with HB and [14] are shown in Figure 2. As shown in Figure 3 , in order to simplify the models, the symmetric models are utilized to calculate the stress distribution under the conditions of different damage state at the first dangerous point. Stress changing of smooth specimen during damage evolution. In Figure 3 , different colors demonstrate that the areas are in different stress states with the damage value increasing at the dangerous point. When the damage value of the first dangerous point reaches 0. And the relative life increment is , when damage value of dangerous point jumps from 0. The increment is , when the damage value increases from 0. After failure of the first dangerous point, the rapid decline of bearing area of component from to illustrates that component has totally failed and the corresponding life increment is small, which proves the correctness of the assumption made in Section 4. As shown in Table 1 , fatigue life can be predicted by damage mechanics-FEM under the other loading conditions, the analysis error of which satisfies the engineering requirement. The fatigue life prediction results of smooth specimen. The Fatigue Simulation of Notched Specimens The material parameters confirmed by smooth specimens test results are used to estimate the fatigue life of the notched specimens. Axial symmetry model is adopted in order to improve calculation efficiency. Moreover, finite element mesh is refined to increase the accuracy of stress states around the notch of specimen. Simulation fatigue tests are performed under the conditions that the stress concentration factor of specimen is 3 in the Practical Handbook of Engineering Materials [14] and the nominal maximum stress of the notched specimen equals MPa. The size of the model is in accordance with HB Stress changings are shown in Figure 4 , when the damage increment value equals 0. The total life increment of three statistics processes from the beginning to is , , and separately. And the relative life increment from the former statistics to is , , and separately. Stress changing of notched specimen during damage evolution. Similar to those in Figure 3 , the elements with higher stress represent that the elements are under stress concentration condition. On the contrary, the elements behind the notch with lower stress values denote that the elements have fully failed. With the increasing of loading cycles, the area with lower stress states will extend from the notch region to the inner part. After cycles of loading, the extending speed of failure area increases faster. The failure life of first dangerous element of notched specimen is during the analysis process of the first 10 modeling cycles. Therefore, compared to the total fatigue life of the notched specimen, damage evolution life in the elements has a higher proportion during the failing process. It could be found that the relative life increment of first analyzing modeling loop is at least one order of magnitude greater than life increment during the subsequent same number of modeling cycles. With failure units increasing, both less bearing area and higher stress state at the dangerous points contribute to the increase of failure rate. The life increment of the third modeling cycles is much smaller than that of the second modeling cycles, so the life with crack extending to 0. The process of simplification can forecast an acceptable fatigue life and reduce the computing time. The fatigue life prediction results of notched specimen subjected to other nominal stresses are shown in Figure 5.

Chapter 2 : Material Fatigue Definition

In materials science, fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading.

Material fatigue is a phenomenon where structures fail when subjected to a cyclic load. This type of structural damage occurs even when the experienced stress range is far below the static material strength. Fatigue is the most common source behind failures of mechanical structures. The process until a component finally fails under repeated loading can be divided into three stages: During a large number of cycles, the damage develops on the microscopic level and grows until a macroscopic crack is formed. The macroscopic crack grows for each cycle until it reaches a critical length. The cracked component breaks because it can no longer sustain the peak load. For certain applications, the second stage cannot be observed. A microscopic crack instead grows rapidly, causing sudden failure of the component. The details of the last two stages are usually considered within the topic of fracture mechanics. The term fatigue applies mainly to the first stage. There is, however, some overlap between the disciplines and the measured number of cycles to fatigue often includes the last two stages as well. Fatigue Variables Under the influence of a nonconstant external load, the state in the material also varies with time. The state at a point in the material can be described by many different variables such as stress, strain, or energy dissipation. The fatigue process is typically viewed as controlled by a specific such variable. A load cycle is defined as the duration from one peak in the studied variable to the next peak. In a general case, all cycles do not have the same amplitude. For a superficial discussion, it can, however, be assumed that the fatigue-controlling state variable has the same value at the start and end of each load cycle. In elastic materials, a cyclic load causes a periodic-cyclic stress response. For such cases, the load cycle is easily defined. This is illustrated by the figure below, where stress is the fatigue-controlling state variable. Figure depicting common variables that are used to predict material fatigue. Common variables used for fatigue prediction. For any detailed analysis, the mean stress, however, must be taken into account as well. A tensile mean stress increases the sensitivity to fatigue, whereas a compressive mean stress allows for higher stress amplitudes. The material response to a sequence of load cycles is highly dependent on the nature of the external load, which can be periodic, random, and even consist of repeatable blocks. For the latter two cases, the description of the load cycle is not as easy as in a pure periodic case; it requires special procedures. Material response of a frame with a cutout that is subject to three generalized loads. Frame with a cutout that is subjected to a random load. The time histories of three generalized loads â€" two bending moments and one twisting moment â€" are shown. Stress contours represent the material response to a corresponding unit load. Low- and High-Cycle Fatigue Fatigue analysis is not always based on a stress response. This branch, however, has historically received much attention since the majority of research has been performed in regimes where stress-based models are useful. Based on the number of load cycles needed to produce a crack, it is customary to make a distinction between low-cycle fatigue LCF and high-cycle fatigue HCF. The limit between the two is not distinct, but it is typically of the order of 10, cycles. The physical rationale is that in the case of HCF, the stresses are low enough that the stress-strain relation can be considered elastic. When working with HCF, the stress range is usually used for describing the local state. For LCF, meanwhile, strain range or dissipated energy are common choices. Fatigue Models Research in the field of fatigue first began in the 19th century and its continuation has resulted in a number of methods for fatigue prediction. One of the classical models is the so-called S-N curve. This curve relates the number of cycles until failure i. The general trend is that a longer lifetime is obtained with a decrease in stress amplitude. Some materials exhibit a stress threshold in fatigue testing. At stresses below this threshold, known as the endurance limit, no fatigue damage is observed and components can operate for an infinite lifetime. Not all materials have an endurance limit, though. Therefore, they can fail due to fatigue even at low levels of stress. An S-N curve, one of the classical models for fatigue prediction. S-N curve for a material with an endurance limit solid line and without an endurance limit dashed line. In multiaxial loading, the directions or locations of the external load vary and thus deform a structure in different directions. This means that at each time instance, a full stress or strain tensor rather than a scalar value must be evaluated. This is often treated by critical plane methods, where many planes in space are investigated in search for the critical one where fatigue is expected to be initiated. In random loading, the stress cycle cannot be described with single stress amplitudes since each cycle is different from the next. To predict fatigue, the full stress history must be transformed into a stress spectrum that can be related to fatigue in the next step of the analysis. The Rainflow counting algorithm can be used to define a set of stress amplitudes with corresponding mean stresses. The Palmgren-Miner linear damage rule is a popular way to predict fatigue under such a set of different stress levels. A simulation plot depicting the use of the Rainflow counting algorithm to predict stress cycle distribution. Stress cycle distribution according to the Rainflow counting algorithm. Random loading is common in vibrational fatigue where structures experience dynamic loads. Since the stress depends on the excitation frequency, the fatigue evaluation can be made in the frequency domain using, for example, power-spectral density methods. In the case of certain materials, fatigue life is highly influenced by the number of micromechanical defects. For instance, a defect in the vicinity of the stress concentration significantly reduces the lifetime of a component as compared to a component with a defect that is far from the stress concentration. Probabilistic methods can be used to handle these types of applications. When it comes to selecting a model for fatigue prediction, there is no general choice. The applicability of each model depends on both material and loading type. It is, however, possible to narrow the number of applicable models by simply asking a few qualitative questions as seen in the blog post " Which Fatigue Model Should I Choose? Fatigue Material Data A fatigue evaluation requires both a fatigue model and material data. Each model requires a different set of material parameters that can be obtained from material tests. Fatigue testing can be a rather time-consuming process, as a single test can run for many cycles before fatigue is observed. In high-cycle fatigue, for example, a specimen can last for one million cycles before it fails. Furthermore, the influence of the microstructure on fatigue sensitivity introduces a scattering in the test results. This is caused by the fact that materials are inhomogeneous on the micromechanical level. Take an alloy, for instance, where there are crystallized grains and the grain boundaries cause stress concentrations. In a metal cast, there might even be pores formed during the solidification process. Therefore, on a local scale, the strains may be much larger than the macroscopic average values and dislocations within the crystals could occur. Because the location of such micromechanical irregularities are more or less randomly distributed, there is a large scattering in the number of load cycles that a certain type of component can be subjected to, even if the external load is well defined. Because of this, a large number of specimens need to be tested before reliable fatigue data is found. Plot of fatigue material data using an S-N curve. S-N curve for different components of the one material. The black squares represent results from individual tests and indicate the scattering of data. When evaluating test results, it is important to consider statistical effects as well. Here are two examples of such effects: If two sets of bars with different diameters are tested in tension with the same nominal stress, the larger one appears to have a shorter lifetime. The reason is that, within a larger volume of material, the risk of finding a microscopic defect of a certain size is greater. If the same type of bar is tested when subjected to both tensile and bending loads, but giving the same peak stress, the one tested due to bending appears to have a longer lifetime. During bending, only a small volume of the material is subjected to the greatest stress. Additionally, effects such as surface treatment and operating environment will further influence the fatigue strength. The combination of all of these effects as well as the consequences of a potential failure must be taken into account when transforming measured data into allowable values for a certain structure.

Chapter 3 : eFatigue - Thermal Mechanical Technical Background

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Fatigue life[edit] The American Society for Testing and Materials defines fatigue life, Nf, as the number of stress cycles of a specified character that a specimen sustains before failure of a specified nature occurs. Dark area of striations: In metal alloys, and for the simplifying case when there are no macroscopic or microscopic discontinuities, the process starts with dislocation movements at the microscopic level, which eventually form persistent slip bands that become the nucleus of short cracks. Macroscopic and microscopic discontinuities at the crystalline grain scale as well as component design features which cause stress concentrations holes, keyways, sharp changes of load direction etc. Fatigue is a process that has a degree of randomness stochastic , often showing considerable scatter even in seemingly identical samples in well controlled environments. Fatigue is usually associated with tensile stresses but fatigue cracks have been reported due to compressive loads. Fatigue life scatter tends to increase for longer fatigue lives. Materials do not recover when rested. Fatigue life is influenced by a variety of factors, such as temperature , surface finish , metallurgical microstructure, presence of oxidizing or inert chemicals, residual stresses , scuffing contact fretting , etc. High cycle fatigue strength about to cycles can be described by stress-based parameters. Low cycle fatigue loading that typically causes failure in less than cycles is associated with localized plastic behavior in metals; thus, a strain-based parameter should be used for fatigue life prediction in metals. Testing is conducted with constant strain amplitudes typically at 0. Timeline of fatigue research history[edit] Micrographs showing how surface fatigue cracks grow as material is further cycled. Wilhelm Albert publishes the first article on fatigue. He devised a test machine for conveyor chains used in the Clausthal mines. William John Macquorn Rankine recognises the importance of stress concentrations in his investigation of railroad axle failures. The Versailles train wreck was caused by fatigue failure of a locomotive axle. Joseph Glynn reports on the fatigue of an axle on a locomotive tender. He identifies the keyway as the crack origin. The Railway Inspectorate reports one of the first tyre failures, probably from a rivet hole in tread of railway carriage wheel. It was likely a fatigue failure. Eaton Hodgkinson is granted a "small sum of money" to report to the UK Parliament on his work in "ascertaining by direct experiment, the effects of continued changes of load upon iron structures and to what extent they could be loaded without danger to their ultimate security". Braithwaite reports on common service fatigue failures and coins the term fatigue. He concludes that cyclic stress range is more important than peak stress and introduces the concept of endurance limit. Sir James Alfred Ewing demonstrates the origin of fatigue failure in microscopic cracks. Cadwell publishes first rigorous study of fatigue in rubber. Weibull An S-N curve model. Manson explain fatigue crack-growth in terms of plastic strain in the tip of cracks. Tatsuo Endo and M. Elber elucidates the mechanisms and importance of crack closure in slowing the growth of a fatigue crack due to the wedging effect of plastic deformation left behind the tip of the crack. Miller observe that fatigue life under multiaxial conditions is governed by the experience of the plane receiving the most damage, and that both tension and shear loads on the critical plane must be considered. This is a graph of the magnitude of a cyclic stress S against the logarithmic scale of cycles to failure N. This process is sometimes known as coupon testing. For greater accuracy but lower generality component testing is used. Analysis of fatigue data requires techniques from statistics , especially survival analysis and linear regression. The progression of the S-N curve can be influenced by many factors such as stress ratio mean stress , loading frequency, temperature , corrosion , residual stresses, and the presence of notches. A constant fatigue life CFL diagram [19] is useful for the study of stress ratio effect. The Goodman-Line is a method used to estimate the influence of the mean stress on the fatigue strength. Probabilistic nature of fatigue[edit] As coupons sampled from a homogeneous frame will display a variation in their number of cycles to failure, the S-N curve should more properly be a Stress-Cycle-Probability S-N-P curve to capture the probability of failure after a given number of cycles of a certain stress. Probability distributions that are common in data analysis and in design against fatigue include the log-normal distribution , extreme value distribution , Birnbaumâ€"Saunders distribution , and Weibull distribution. Complex loadings[edit] Spectrum loading In practice, a mechanical part is exposed to a complex, often random , sequence of loads, large and small. In order to assess the safe life of such a part: For multiaxial loading[edit] Since S-N curves are typically generated for uniaxial loading, some equivalence rule is needed whenever the loading is multiaxial. For simple, proportional loading histories lateral load in a constant ratio with the axial , Sines rule may be applied. For more complex situations, such as nonproportional loading, critical plane analysis must be applied. Miner [20] popularised a rule that had first been proposed by A.

Chapter 4 : Fatigue XII : Twelfth International Conference on Fatigue Damage of Structural Materials

The twelfth biennial International Conference on Fatigue Damage of Structural Materials will be held in scenic Cape Cod at the DoubleTree by Hilton Hotel, Hyannis, Massachusetts from the September

Oxide damage will occur when the strain range exceeds a threshold for oxide cracking. Phasing is represented by the ratio of thermal and mechanical strain rates. Oxidation rate is determined by the effective parabolic oxidation constant, Kpeff. Creep Damage Model The creep damage formulation suggested by Neu and Sehitoglu is also employed in this study. Microstructural creep damage differs in tension and compression. It is commonly assumed that microcracks do not form and grow in compression. Here, K is the drag stress which will be defined in the next section. A phasing factor fcr is also introduced to account for different creep damage mechanisms such as intergranular or transgranular cracking. The combined effects of both creep and plasticity are treated as inelastic strains. At lower stresses, time dependant creep dominates the behavior. Plasticity dominates at higher stresses. A drag stress, K, is introduced into the formulation. The drag stress is an internal state variable that is related to the strength of the material. It is the stress that defines the transition from creep to plasticity dominated deformation. It is not constant but depends on the temperature. Other forms are possible. Simplified Material Properties TMF mechanisms are complicated and influenced by the material microstructure, environment and external loading and a complete set of material data is preferred. Twenty seven material modeling constants means that only a few materials have been fully characterized. Yet, life assessments must frequently be made in the early stages of design before a complete set of materials data is available. As a result, there is a need to make estimates of the material properties from other more readily available data. In this paper, simplified material properties are employed. They are based on a classification system, low carbon steels, alloy steels, aluminum, etc. These materials will be designed as reference materials. Properties from these materials will be modified to account for microstructural differences between materials within a given class. Fatigue constants are always needed for the analysis. Both creep and oxidation damage models have a phasing factor. The phasing factor is shown in Figure 6 as a function of the thermal and mechanical strain ratio. This factor determines the dominant failure mechanism, creep or oxidation. As a general rule creep will dominate in-phase TMF loading. Oxidation will dominate for both isothermal and out-of-phase TMF. It should be noted that many TMF problems involved constrained heating and cooling which result in out-of-phase loading. In this case, knowledge of the creep properties is unnecessary because only the oxidation and fatigue behavior is important. Figure 6 Phasing Constants for Oxidation and Creep Fatigue Constants Many correlations between fatigue and tensile properties have been proposed. Many of them have been validated only for steels. Engineering Materials and Technology, Vol. It is based on the elastic modulus, E, ultimate strength, Su, and true fracture strain, ef. Oxidation Constants Oxidation is dominated by the matrix material rather than microstructure in most alloys. As a first approximation, alloys of a similar matrix are expected to have the same oxidation behavior. No adjustments are needed for microstructure and all materials of the same class will have the same behavior. Creep Constants Creep is a process that is driven by diffusion either in the bulk material or along the grain boundaries. Creep damage should be directly related to the creep rate and rupture life. Equation 7 for creep damage can be divided into two terms, one for temperature and one for stress dependence. Figure 7 shows a Larson-Miller plot for various alloys. Two materials with the same value of the Larson-Miller parameter, PLM, will have the same time and temperature dependence. Note that the lines describing the material behavior are nearly parallel for a given class of materials. For example, the difference between low carbon and Cr-Mo steel is essentially a shift in stress level. This observation allows us to estimate the behavior of other materials in the same class. Exponents such as m are an indication of the mechanism and are not expected to change. This leaves a single constant, Acr, that will depend on the microstructure. As a first approximation, this constant can be scaled from the reference material data. Two materials with the same PLM will have the same creep damage so that the integrand of creep damage must also be the same for both materials. In Figure 7, consider low carbon and C-Mo steel. Let the creep strength be denoted as S and the creep strength of the reference material as S ref. Manipulating the equation for creep damage and eliminating the temperature terms results in an approximate expression for the constant Acr. Figure 7 Larson Miller Parameters Microstructural effects are indirectly included in the creep damage formulation by normalizing the stress by the drag stress K. Drag stress will also be directly related to the materials creep strength since the drag stress represents the transition between creep and plasticity dominated behavior. Differences between materials within a class are modeled by changes in the drag stress. Constitutive Equation Constants Stresses are not included in the fatigue and oxidation models, only the creep damage model. In the unified constitutive models no attempt is made to separate the creep and plasticity strains, they are all considered as inelastic strains. The exponential terms are related to high temperature creep deformation. Following the same arguments used for determining creep damage constants, the activation energy and exponents are expected to be a constant for alloys within a class of materials. The remaining two constants Ao and K will depend on the material microstructure. Drag stress should scale directly with the materials strength, either creep strength or yield strength. The constant Ao is assumed to remain constant. A very simple model for approximating TMF material constants is proposed, simply adjust the material drag stress in proportion to the material strength. Creep strength is preferred but room temperature yield strength could be employed when creep data is not available. Comparison With Experiments Two of the datasets analyzed are presented here. The basis of comparison is the computed TMF lives because our objective is to make estimates of fatigue lives not reproduce material modeling parameters. The first dataset analyzed is that shown in Figure 2 for steel. The reference data employed was steel. Creep strength data was not available for both materials so the yield strength was used. Fatigue constants were obtained from the SAE handbook for steel Yield strengths for and steel were obtained from www. It lists the yield strengths as and MPa for and steel respectively. Before performing the calculations the drag stress constants were reduced by a factor of 0. No other changes in the oxidation, creep or constitutive equation constants were made. Results of the analysis are given in Table 1. In addition to the experimental and calculated fatigue lives, the relative contribution of each of the three damage mechanisms is given.

Chapter 5 : International Conference on Fatigue Damage of Structural Materials X - Materials Today

Proceedings of the Eleventh International Conference on Fatigue Damage of Structural Materials The eleventh biennial International Conference on Fatigue Damage of Structural Materials was held in Hyannis, Massachusetts from the September

Chapter 6 : Fatigue (material) - Wikipedia

16 people interested. Check out who is attending exhibiting speaking schedule & agenda reviews timing entry ticket fees. edition of International Conference on Fatigue Damage of Structural Materials will be held at DoubleTree by Hilton Hotel Cape Cod - Hyannis, Barnstable starting on 16th September.

Chapter 7 : A Modified Fatigue Damage Model for High-Cycle Fatigue Life Prediction

Fatemi A and Yang L (), Cumulative fatigue damage and life prediction theories: A survey of the state of the art for homogeneous materials, Int. J. Fatigue 20, 46 Sidoroff F and Subagio B (), Fatigue damage modeling of composite materials from bending tests.