Chapter 1 : Paulin Research Group | More Applicable Data for the Pipe Stress Engineer

Fatigue, Fracture, and Damage Analysis. In a paper presented at the PVP Conference, the author showed that with regard to a process zone at the root of a.

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

This paper reviews and summarizes the development and recent progress of methods of stochastic fatigue, fracture and damage analysis. Topics covered include structural fatigue, structural fracture, cumulative damage, maintainability and inspection and structural damage.

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 3 : Ali Fatemi, Ph. D. - Mechanical Engineering - The University of Memphis

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Chapter 4 : FATIGUE CONCEPTS: Fatigue, Fracture Mechanics & Damage Tolerance

Advanced Damage Tolerance Analysis | *Aging Aircraft Course Typical duration of class is four days, though longer and shorter versions are possible using the same syllabus.*

Chapter 5 : Fatigue (material) - Wikipedia

Fatigue, Fracture Mechanics, and Damage Analysis Inelastic, Nonlinear and Limit Load Analysis Stress Classification and Design by Analysis Methodologies.