

Japanese Aerospace Literature This month: *Fatigue Life*

A94-28239 Miner's rule for fatigue life of short carbon fiber reinforced poly-ether-ether-ketone. H. NOGUCHI, A. NISHIZAWA, H. NISITANI (Kyushu Univ., Fukuoka, Japan), and Y.-H. KIM (Korea Mat. Univ., Pusan, Republic of Korea), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 489, June 1994, pp. 672-678. In Japanese. 20 Refs. Documents available from Aeroplus Dispatch.

The actual load on mechanical structures does not always have a constant stress amplitude. Therefore, it is very important for the prediction of fatigue life under complex load to investigate whether Miner's rule is valid or not. In this paper, rotating-bending fatigue tests for short carbon-fiber reinforced poly-ether-ether-ketone (CFRPEEK) under two-step loading were carried out to investigate the applicability of Miner's rule. In case of a short fiber reinforced composite like CFRPEEK, the fatigue process should be treated by dividing it into two stages, that is, one where the fatigue damage concentrates on the edge of the short carbon fiber, and the other where the fatigue damage concentrates on near the fatigue crack's tip. From the result of the experiments, it was concluded that Miner's rule can be applied to the both stages in the short fiber reinforced composites as in the case of metals, and thus Miner's rule holds well under two step loading in CFRPEEK. (Author)

A94-28238 Effect of shot peening on fatigue strength of Ti-6Al-4V. Y. KITSUNAI, M. TANAKA, and E. YOSHIIHISA (Research Inst. for Industrial Safety, Kiyose, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 489, June 1994, pp. 666-671. In Japanese. 10 Refs. Documents available from Aeroplus Dispatch.

The effects of shot peening on the axial fatigue properties of Ti-6Al-4V were examined in connection with residual stress and microstructure. Double edge notched plate specimens with the stress concentration factor 1.63 were prepared. By shot peening, compressive residual stress was introduced into the surface layer of approximately 70 microns in depth, which showed the maximum value of 600 MPa. Fatigue tests were carried out at $R = 0.05$. The fatigue strength of the shot peened specimens increased by about 1.3 times that of the unpeened specimens. The fatigue crack initiation site in the shot peened specimens was at about 150-180 microns below the specimen surface. In the unpeened specimens, however, a fatigue crack was initiated within a phase microstructure at the specimen surface of the notch root. The increase of fatigue strength in the shot peened specimens might be due to a shift of the initiation site from the surface to the subsurface. The surface residual stress in the shot peened specimen measured by an X-ray diffraction method slightly decreased during cyclic loading. (Author)

N94-37416 Creep-fatigue interaction property of a nickel-base heat-resistant alloy Hastelloy XR in simulated HTGR helium gas environment. H. TSUJI (Japan Atomic Energy Research Inst., Tokyo, Japan) and H. NAKAJIMA (Japan Atomic Energy Research Inst., Tokyo, Japan), Documents available from Aeroplus Dispatch.

The properties of Hastelloy XR, which is an alloy developed as the structural material for high-temperature components of the HTTR, under creep-fatigue interaction conditions were examined by performing a series of axial strain controlled fully reversed fatigue tests in the simulated HTGR helium gas environment at 700, 800, 900, and 950 C. Two types of evaluation techniques, i.e., the life fraction rule and the ductility exhaustion one, were applied for the evaluation of the creep damage during the tensile strain holding. The fatigue life reduction due to the strain holding is observed even at hold times of 6 seconds, and the saturation point of the fatigue life reduction shifts to the shorter hold time side with increasing temperature. The life fraction rule predicts an excessively conservative value for the creep damage. The ductility exhaustion rule can predict the fatigue life under the effective creep condition much more successfully than the life fraction one.

A95-17494 Fatigue strength of silicon nitride ceramics at high temperatures. H. HOHJO, A. YAMADA, and K. SARUKI (Toyota Central R&D Lab., Inc., Aichi, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 44, No. 496, Jan. 1995, pp. 128-132. In Japanese. 13 Refs. Documents available from Aeroplus Dispatch.

Static and cyclic bending fatigue tests were carried out on two types of S13N4 ceramics at high temperatures in air. The effect of the viscosity of grain-boundary phase on fatigue strength was investigated; experimental results show that the effect of stress cycling on fatigue strength varies depending upon the following three temperature levels in relation to the viscosity of the grain-boundary phase. In the temperature region below the softening point of the grain-boundary phase, the cyclic fatigue strength was lower than the static fatigue strength; this may be due to the acceleration of crack propagation rate by stress cycling. Very few specimens had fractured at 10 exp 7 cycles. The average flexural strength of these survival specimens was over 20 percent higher than the average static strength of virgin specimens at the same temperature. In the temperature region where the grain-boundary phase is softened, the cyclic fatigue strength was lower than the static fatigue strength. The longer experimental life in cyclic fatigue is attributed to the high loading rate, which generates smaller strain. (Author)

A95-17491 Life analysis for fatigue-creep situation of Cr-Mo-V rotor steel. T. GOTO, T. KONISHI, Y. KADOYA (Mitsubishi Heavy Industries,

Ltd., Takasago, Japan), J. SATO, T. IKUNO, and K. YOSHIMURA (Kansai Electric Power Co., Inc., Amagasaki, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 44, No. 496, Jan. 1995, pp. 16-22. In Japanese. 15 Refs. Documents available from Aeroplus Dispatch.

Life analysis for fatigue-creep situations of Cr-Mo-V rotor steel was studied using the results of fatigue tests conducted with strain hold and stress hold at 500 C. Linear damage theory and the ductility exhaustion rule are applicable when the results of high-temperature low-cycle fatigue tests and creep rupture tests are available. However, both methods are not appropriate for accurate life analysis; the former tends to yield an unsafe estimated life and the latter tends to yield too generous results. The Priest and Ellison (1981) method was applied to the experimental results obtained by the authors. It was found that the method is excellent for accurate life analysis. When the combined deformation map ductility exhaustion approach is applied, the necessary creep rupture ductility can be substituted by the product of minimum strain rate and rupture time, both of which are obtainable by relatively short time creep tests. (Author)

A95-11786 Fatigue damage and fracture of carbon fabric/epoxy composites under tension-tension loading. K. TAKEMURA and T. FUJII (Doshisha Univ., Kyoto, Japan), *JSME International Journal, Series A: Mechanics and Material Engineering* (ISSN 1340-8046), Vol. 37, No. 4, Oct. 1994, pp. 472-480. 16 Refs. Documents available from Aeroplus Dispatch.

The degradation of a plain woven carbon fiber/epoxy composite under tension-tension fatigue loading was studied. An almost flat S-N diagram was obtained for this composite. As high as 85 percent fatigue strength of the static strength at 10 exp 6 cycles was recorded. A new specimen configuration was developed and used. That is, the specimen has two narrow sections. After the specimen fails at one section under static or cyclic loading, the residual strength of the other section will be statically measured. The residual strength for specimens failing under static and cyclic loadings is higher than the static strength for the virgin specimen. A typical S-shape stiffness reduction against logarithmic cycle number is found for high-cycle fatigue specimens. However, sudden fatigue death of the specimens occurs with no indications in both S-S curves and AE events. Parameters of the parabolic function which fits the convex S-S curve are more sensitive to the stiffness reduction than the observed stiffness. Microscopic examination of the fracture surface was conducted. From those observations, a fatigue damage process model is proposed. (Author)

N94-25583 Study on evaluation of crack generation and crack growth behaviors under static loading at high temperature and under combined loading (Koon seikaju oyobi kurikaeshi kajuka no kiretsu hassei oyobi seicho kyodo no hyoka ni kansuru kenkyu). K. YAGI, M. TABUCHI, K. YOKOKAWA, O. KANAMARU, K. KUBO, T. OBA, and F. SUZUKI (Yokohama National Univ., Japan), In its *Bulletin of National Research Institute for Metals in Fiscal Year 1993*, No. 14, pp. 369-377 (SEE N94-25544 07-26). Documents available from Aeroplus Dispatch.

Creep, crack generation under creep fatigue, and creep crack growth were investigated in correlation with microscopical observation with the purpose of improving the evaluation level of creep crack growth behaviors and rupture lives under creep-fatigue loading. A creep crack growth test was conducted on 316 stainless steels and NCF800H alloys to find the correlation between the creep crack growth rate (da/dt) and the breaking style parameter C . The results showed that the $da/dt - C$ correlation was closely related to the breaking style, and it could be classified into two groups based on the breaking style. However, this correlation was not true if a creep damage ranged over a large area around the crack end. A creep fatigue test was conducted under combined loading on coarse grained and fine grained 321 stainless steels. Determination of the creep damage amount and fatigue damage amount by linear life damage rules revealed that the correlation between these two amounts was related to the breaking style, and furthermore, to the breaking process as well. (Author)

N94-25567 Study on improvements in fretting fatigue characteristics of high strength structural member (Kokyodo kozo zairyo no furetingu hiro tokusei nojo ni kansuru kankyu). M. SUMIDA, K. NAKAZAWA, R. HAMANO, N. MARUYAMA, Y. KAWABE, S. NISHIJIMA, T. FUJII, and K. SAITO, In its *Bulletin of National Research Institute for Metals in Fiscal Year 1993*, No. 14, pp. 207-218 (SEE N94-25544 07-26). Documents available from Aeroplus Dispatch.

Pad-pressure effects on the fretting fatigue lives of high tension steel and Ti-6Al-4V alloy were investigated. It was clarified that fairly small pressure would minimize the fatigue lives. This is considered to be caused by the centralization of friction and pressure to small contact surfaces. Research was made regarding how cathode anti-corrosion modification affects on fretting fatigue behavior of high tension steel in sea water. Fretting fatigue strength under natural corrosion in sea water deteriorated remarkably compared with that in the air. However, the cathode anti-corrosion modification improved the fretting fatigue strength in sea water and made it higher than that in the air. Environmental influence on fretting fatigue behavior of Ti-6Al-4A alloy was also investigated. The fretting fatigue strength in artificial sea water is generally lower than that in the air. The fretting fatigue strength in LiCl-CH₃OH was

approximately twice as strong as regular fretting fatigue strength. The corrosion fatigue behavior of high strength steel in sea water was researched. Thin films were coated on the steel surfaces by magnetron sputtering and ion mixing. The cohesion of the films effectively improved by the two methods together, preventing the fatigue life from deteriorating due to hydrogen embrittlement. (Author)

N94-25548 Preparation of creep data sheet: Material strength data sheet (Kuripu deta shito no sakusei: Zairyo kyodo deta shito Report No. 3). C. TANAKA, K. YAGI, S. IKEDA, H. ITO, E. BABA, M. SHIMIZU, H. TANAKA, K. YOKOKAWA, H. NAGAI, O. KANAMARU et al., In its *Bulletin of National Research Institute for Metals in Fiscal Year 1993*, No. 14, pp. 43–63 (SEE N94-25544 07-26). Documents available from Aeroplus Dispatch.

Continuing from the first and the second term, creep rupture data sheet on metals for high temperatures was continued targeting for 100,000 hours. Creep strain data sheet for elastic analysis, conceived in the second term was carried out this term. Additionally, research was planned into the Cr group steel, which is increasingly in demand for high temperature equipment, and material sampling and testing commenced accordingly. In 1986, the creep data sheet (B Version) was published for the first time, including the creep rupture data exceeding final target of 100,000 hours. Since then, B versions were published on 12 different materials this term. There has been much research using the data from creep data sheets and test samples, including creep strain characteristics, stress relaxation characteristics, creep rupture characteristics and life estimate, with substantial results. In the creep test technology aiming for highly reliable data, deterioration factors of thermocouples were investigated. The results from creep data sheets and related research contributed to improvement in strength reliability of metals at high temperatures. (Author)

N94-25547 Interactions between corrosion fatigue and stress corrosion crack on steel for light water reactors (Keisuiroyo kinzoku zairyo no fushoku hiro-oryoku fushokuware sogo sayo ni kansuru kenkyu). N. NAGATA, T. ISHIHARA, S. MATSUSHIMA, Y. KATADA, S. SATO, and S. OHASHI, In its *Bulletin of National Research Institute for Metals in Fiscal Year 1993*, No. 14, pp. 29–42 (SEE N94-25544 07-26). Documents available from Aeroplus Dispatch.

In order to evaluate material safety in the coolant environment, investigation is conducted concerning the interactions between corrosion fatigue and stress corrosion crack as well as environment factors which influence the incidence and crack growth in hot, high pressure water. Rolling alloy steel JIS (Japanese Industrial Standards) SQV2A used for pressure vessels and forging material SFVQ1A served as test samples. In the compound load experiment of fatigue and tension at low strain rate, no notable interactions were recognized which may affect the crack growth rate. It was found that the crack growth rate is proportional to the density of dissolved oxygen, and inversely proportional to the flow rate. The faster the crack growth rate was, the lower the corrosion electric potential was, especially in materials including more sulfur. No distinct correlation was found between the corrosion electric potential and dissolved oxygen. In dissolution study of MnS between cracked fractures, dissolution occurred more easily (at lower temperature) in crevices than on free surfaces. In the fatigue test in hot, high pressure water fatigue life of SQV2A material found more dependency on the strain rate (slower strain rate shortened the fatigue life) than that of SFVQ1A material. (Author)

A94-23161 Mechanism of rolling contact fatigue and Mode II fatigue crack growth—A proposal on a Mode II fatigue crack growth test method. A. OTSUKA (Gifu Polytechnic College, Japan), H. SUGAWARA (Brother Industries, Ltd., Product Development Center, Nagoya, Japan), M. SHOMURA (NGK Insulators, Ltd., Nagoya, Japan), M. AOYAMA, S.-K. YOO (Nagoya Univ., Japan), and M. SHIBATA (Koyo Seiko Co., Ltd., Research Lab., Kashiwara, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 484, Jan. 1994, pp. 55–61. In Japanese. 13 Refs. Documents available from Aeroplus Dispatch.

From the fractographic observation on silicon nitride specimens failed under rolling contact fatigue, it has been found that the crack initiation in silicon nitride specimens subjected to rolling contact fatigue is induced by cyclic subsurface shearing stress. Though these subsurface cracks are produced in the direction parallel to the cyclic shearing stress, cracks grow in the direction near the plane of the maximum tensile stress if Mode II loading is applied to them. The difference between the crack growth in simple Mode II loading and the crack growth in rolling contact fatigue is, we suppose, whether or not there is a superimposed compression stress. Based on this hypothesis, we developed an apparatus to obtain intrinsic Mode II fatigue crack growth characteristics, as a simplified model of determining the subsurface crack growth in rolling contact fatigue. Some preliminary results on $da/dN - \Delta K$ (II) relations were obtained by using this apparatus on steel and aluminum alloys. (Author)

A94-23160 Effects of pre-straining and aging on fatigue crack growth behavior of aluminum alloy under high-low two-step varying load conditions. T. TANAKA (Ritsumeikan Univ., Kyoto, Japan), Y. KATOH (Nakanon Automotive College, Gifu, Japan), and H. NAKAYAMA (Osaka Sangyo Univ., Daito, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 484, Jan. 1994, pp. 48–54. In Japanese. 18 Refs. Documents available from Aeroplus Dispatch.

A series of fatigue crack growth tests was carried out under two-step varying load conditions to reveal the fundamental characteristics of fatigue-crack-growth behavior under varying load conditions, and an empirical law governing the crack growth rate during the retardation period, observed after the load change from high to low load amplitudes was established. This report describes the results of fatigue crack growth tests carried out on an Al alloy CT specimen to investigate precisely the effects of prestraining and aging treatment on the crack growth behavior during the retardation period under two-step varying load conditions. The results indicated that the crack growth rate under constant amplitude load conditions was not affected by the prestraining and the aging treatment, but that the crack growth rate during the retardation period was remarkably influenced by these treatments. By taking the above mentioned crack growth behaviors into account, the analytical crack growth law to estimate the crack growth rate in the retardation period, derived empirically in previous studies, was modified to be available for a wide range of material conditions. A reasonable crack growth model was also proposed. (Author)

A94-23157 Effect of shot-peening on suppression of scatter of fatigue strength in Ti-6Al-4V alloy. K. ASAMI and M. HIRONAGA (Musashi Inst. of Technology, Tokyo, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 43, No. 484, Jan. 1994, pp. 12–17. In Japanese. 10 Refs. Documents available from Aeroplus Dispatch.

When Ti-6Al-4V alloy was polished by using diamond paste or No. 400 emery paper, fatigue cracks initiated at the surface and its fatigue strength scattered widely. It was considered that the scatter of fatigue strength depended on the local surface morphology. On the other hand, when the fatigue crack were initiated at the subsurface with shot peening, the scatter of fatigue strength became narrowed remarkably. The fatigue strength of the shot peened specimen, however, decreased again in the long-life region, and no fatigue limit was recognized even after more than 10 exp 7 cycles. This phenomenon might depend on the residual stress distribution. (Author)

A94-20972 Rolling fatigue properties of silicon nitride bearing balls. M. ICHIKAWA, T. TAKAMATSU, T. MATSUO (Univ. of Electro-Communications, Chofu, Japan), N. OKABE, and Y. ABE (Toshiba Co., Yokohama, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 483, Dec. 1993, pp. 1406–1411. In Japanese. 16 Refs. Documents available from Aeroplus Dispatch.

Rolling fatigue tests were carried out on hot isostatically pressed silicon nitride bearing balls. At three load levels of the maximum Hertzian contact pressure $p(\max)$, 13 balls each were tested and the life distribution was studied. It was found that the rolling fatigue life followed approximately a two-parameter Weibull distribution with the shape parameter of alpha about one at each load level. A relationship was found between $p(\max)$ and the median life. Microscopic observation of flaking was also performed, and two types of flaking were found. One was flaking with the depth of the order of 100 microns, and the other was a shallower one. The depth of the former type was found to coincide approximately with the depth at which the maximum shear stress occurred. At lower load levels, the former type was dominant. Frequency of appearance of the latter type increased with an increase in load level. (Author (revised))

A94-20971 A probabilistic approach to the random propagation of collinear two cracks. T. TANAKA (Fukui Prefectural Univ., Japan), A. YAMANE, A. TSURUI, and H. TANAKA (Kyoto Univ., Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 483, Dec. 1993, pp. 1400–1405. In Japanese. 8 Refs. Documents available from Aeroplus Dispatch.

Fatigue life of a plate with two collinear cracks is theoretically investigated with the random variation of crack propagation resistances taken into consideration. Firstly, the crack propagation process is modeled as a bivariate stochastic process governed by a randomized Paris law. Secondly, a joint probability density function of the two crack lengths is derived from the Fokker-Planck equation by using a difference scheme, the initial condition being an approximate solution. Finally, the failure probability of the plate is numerically evaluated and its sensitivity to the initial crack state is examined. (Author (revised))

A94-20970 Reliability analysis on S-N evaluation model. S. SAKAI, H. OKAMURA, and K. SASAKI (Tokyo Univ., Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 483, Dec. 1993, pp. 1395–1399. In Japanese. 5 Refs. Documents available from Aeroplus Dispatch.

It has been shown from the results of round robin tests conducted under VAMAS project that the fatigue property may vary from one researcher to another due to the difference of evaluation models used. It is important to clarify the effect of the S-N evaluation model used on the reliability analysis. In this paper, the fatigue data are fitted to five regression models and the goodness of fit is investigated. The fatigue data are picked from the fatigue database which was provided by JSMS. No significant difference could be found concerning the goodness of fit against the models. However, the results differed slightly depending on the factor used in the goodness of fit. Moreover, the effect of the model on the evaluated fatigue life is investigated for the fatigue under random loads. The fatigue life evaluation was formulated for three regression models and the fatigue life under various rms values was calculated for several materials. The effect of the fatigue model on the evaluation life was clarified. (Author (revised))