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Special Issue on "Fatigue, Cyclic Deformation and Microstructure"

Special Issue

Iron and Steel

Cyclic deformation and fatigue of selected ferritic and austenitic steels : specific aspects(Review)

H. MUGHRABI et al.

Some recent work on the cyclic deformation and fatigue behaviour of selected ferritic and austenitic steels is reviewed. The steels considered are the ferritic plain carbon steels SAE 1010, and SAE 1045, the martensitically or bainitically hardened roller bearing steel SAE 52100 and metastable austenitic steels of the type AISI 304 L. The review deals with several specific aspects. In particular, experimental data are presented and discussed for the following topics : cyclic deformation (hardening/softening) and its temperature dependence, the cyclic stress-strain behaviour in single- and multiple-step tests and in the incremental step test, the characteristic microstructural changes and dislocation mechanisms, cyclic plasticity and Masing or non-Masing behaviour, some effects of mean stress, dynamic strain ageing phenomena and their effects on fatigue life in stress- and strain-controlled tests and, finally, the enhancement of the monotonic strength and the fatigue resistance of metastable austenitic steels by exploitation of the fatigue-induced martensitic deformation, in particular at low temperatures.

Subsurface crack generation in high-cycle fatigue for high strength alloys(Review)

O. UMEZAWA et al.

In order to progress in the understanding of fatigue fracture process for high strength alloys, the previous studies of the subsurface fatigue crack generation are reviewed. A change in crack initiation mechanism from specimen surface to specimen interior often introduces a plateau ("knee") followed by a rather sharp drop in the shape of S-N curve. Various subsurface crack origins are related with microstructural crackings and pre-existing defects. The subsurface initiation site is formed as a Stage I crack. A new explanation of microcrack growth is proposed for the subsurface crack generation process. The subsurface crack size is the most important parameter to determine how the crack becomes a fatal crack. The size highly depends on the maximum cyclic stress range, which implies a ΔK_{th} threshold controlling mechanism. The dislocation structures in high-cycle fatigue are fairly planar for both austenitic steel and titanium alloy.

Effects of texture on fatigue crack propagation of low-carbon steel

T. YAKUSHIJI et al.

Plain bending fatigue tests were carried out on several kinds of hot-rolled low-carbon steel sheets with texture to clarify the effects of texture on fatigue crack propagation. The crack growth rate of each material was determined uniquely by a term $\sigma a^n \iota$, where σa is nominal stress amplitude, ι is the crack length, and n is a material constant. The n exhibited different values according to the materials, whereas there is not so much difference in the σB of each material. The different n in such materials may result from the difference in texture. Moreover, the value of n tended to decrease with an increase in r value, plastic anisotropy ratio. The analysis based on the small-crack growth law, $d\iota/dN = C_3(\sigma a/\sigma B)^n \iota$, in which the effect of a material property was considered, suggested that the effect of texture on the value of C_3 is negligible. The reciprocal of C_3 represents the resistance to small crack propagation in each material.

The effects of straining frequency and stress ratio on polarization current responded to cyclic strain in a commercial iron

E. TADA et al.

Corrosion fatigue tests of a commercial iron were carried out using a cylindrical specimen with a hole in a borate buffer solution containing 5 mol/m^3 NaCl at a constant passive potential. Polarization current behavior induced by strain cycles has been investigated in order to elucidate the effects of straining frequency and stress ratio. The amplitude of polarization current synchronized with the strain cycle and the phase shift between the polarization current and the strain were calculated. The polarization current obtained prior to the crack initiation was found to be the charging and discharging current of the electric double layer capacitance. The corrosion damage increased as increasing the straining frequency in the initial stage of crack propagation. The increased corrosion damage was observed at the reduced stress ratio.

Intermetallics

Fatigue of aluminides and silicides(Review)

N.S. STOLOFF

The fatigue resistance of two major classes of intermetallics, aluminides and silicides, are reviewed in this paper. High cycle fatigue (HCF) and fatigue crack growth (FCG) behavior are emphasized, as both are determined in most cases under stress control. Major experimental variables are composition, microstructure, temperature, state of order, mean stress (or R ratio) and test environment. Results of work on aluminides of titanium, nickel, iron and niobium aluminides are described. Methods to improve stress-controlled fatigue resistance of these alloy systems are reviewed.

Effect of V and Nb addition on the fatigue behaviour of TiAl polysynthetically twinned crystals

H. YASUDA et al.

Effect of V and Nb addition on the fatigue behaviour of TiAl alloys was investigated using polysynthetically twinned (PST) crystals. The cyclic hardening and fatigue life of TiAl PST crystals depended strongly on the orientation and alloying elements. When the stress was applied parallel to the lamellar boundaries at $\phi = 0°$ where ϕ is the angle between the loading axis and lamellar planes, slip occurred across the lamellar boundaries showing strong hardening. When slip occurred in the γ matrix parallel to the lamellar boundaries at $\phi = 45°$, cyclic behaviour and fatigue life were strongly influenced by the V and Nb addition : the fatigue life was prolonged by Nb addition, while V addition reduced the fatigue life.

In the fatigued TiAl PST crystals, numerous deformation twins and $1/2[1\bar{1}0]$ ordinary dislocations were observed in the γ phase depending on the type of domain. Activation of twins and the frequency of cross-slip events for the $1/2[1\bar{1}0]$ ordinary dislocations were very sensitive to additional elements of V and Nb. Since V and Nb addition were expected to decrease and increase the stacking fault energy, respectively, V-doping accelerated twinning and suppressed the cross-slip of the ordinary dislocations. In contrast, a small number of twins were observed and the cross slip of the ordinary dislocations frequently occurred in Nb-doped crystals.

Since deformation twins induced in an early stage of cyclic deformation interrupted the motion of dislocations through γ/γ domain boundaries under cyclic loading and formed highly residual stress, the addition of V reduced the fatigue life.

Plastic deformation behaviour and substructure in CoTi single crystals fatigued at room temperature

A. BEHGOZIN et al.

Cyclic deformation and deformation substructure of CoTi single crystals were examined focusing on operative slip systems and cyclic hardening. Fatigue tests were performed in a tension/compression mode under a fixed amplitude of total strain ($\Delta\varepsilon = \pm 0.1 \sim \pm 0.3\%$) in air at room temperature. CoTi deformed by {110}<001> slips at various strain amplitudes. At $\Delta\varepsilon = \pm 0.1\%$ primary (110) [001] slip was dominant and the stress ampli-

tude gradually increased with number of cycles until it reached a saturated value. As secondary slips were more activated with increasing $\Delta\varepsilon$, cyclic hardening was more accelerated and the fatigue life was shortened. Highly piled-up dislocations composed of primary and secondary dislocations formed strong residual stress fields, resulting in crack initiation and propagation. A large number of dipoles and loops which also contributed to cyclic hardening were produced during the to-and-fro motion of 〈001〉 screw dislocations.

Other Alloys

Low cycle fatigue of Cu-Fe alloy single crystals containing transformable Fe precipitates

M.KATO et al.

Low-cycle fatigue behavior of Cu-1.53 mass%Fe alloy single crystals with and without precipitated γ-Fe particles was examined. Although the γ-Fe particles are coherent and shearable, no cyclic softening was observed. Dislocation structures in solution-treated specimens were similar to those of fatigued pure Cu single crystals. However, in aged specimens, the precipitated γ-Fe particles retard the development of a dislocation structure. As a result, more uniform dislocation distribution compared with that in solution-treated specimens was observed, at least in the initial stages of cyclic deformation. Magnetic measurements revealed that the majority of the γ-Fe particles had transformed martensitically into α-Fe during the fatigue tests. The transformation changes the particle character from "shearable" to "nonshearable". This change enhances the uniform deformation and the homogeneous dislocation distribution and leads to the absence of cyclic softening.

Microstructural development during fatigue of a polycrystalline 3003 aluminum alloy

T.FUJII et al.

Polycrystalline 3003 aluminum alloy has been cyclically deformed at room temperature with constant plastic-strain amplitudes in the range $1\times10^{-4}\sim5\times10^{-3}$. At any strain amplitude, stress saturation was not observed: A monotonic hardening occurred at low plastic-strain amplitudes less than 5×10^{-4}. Sequence of hardening, softening and secondary hardening was found at medium strain amplitudes in the range $1\times10^{-3}\sim3\times10^{-3}$. Dislocation configurations in fatigued samples depended on the strain amplitudes and the number of cycles. At low strain amplitudes less than 1×10^{-3}, loop patches with a particular periodicity in dis location arrangement were formed during the first hardening stage. The labyrinth structure composed of dislocation walls periodically arranged along the {100} planes was formed during the softening stage at the medium strain amplitudes. The stable dislocation configuration after the secondary hardening was found to be the cell structure. The microstructural analysis using transmission electron microscopy is well applicable to the fatigue life assessments of the 3003 aluminum alloy.

Distribution of internal crack initiation sites in high-cycle fatigue for titanium alloys

H. YOKOYAMA et al.

In order to clarify how the internal crack initiation site distributes according to microstructure in high-cycle fatigue, α-β or near α titanium alloys with various microstructure were subjected to fatigue test in liquid nitrogen. The internal crack initiation occurred longer than 10^5 cycles at 77K. The initiation site was a facet or its aggregate which originated from α grain transgranular cracking in each material. In equiaxed α structures, the location of initiation site was obviously restricted to near the specimen surface (*i.e.*10-200μm deep from the specimen surface). In acicular α structures, the location was more or less near the specimen surface and more interior cases were also seen, which were associated with a larger initiation site size. In elongated α structure, on the contrary, the location was scattered from the vicinity of specimen surface to the center in fracture surface. The size of the internal crack initiation sites was evaluated, and the location of the sites was discussed from the viewpoints of the cyclic stress and their size.

Constant ΔK fatigue crack growth tests under programmed humidity cycle conditions-as a tool to evaluate the effect of humidity on fatigue crack growth of Al-Li alloys-

S.KUMAI et al.

The effect of the relative humidity of the laboratory air on the fatigue crack growth rate in 8090 Al-Li alloys has been examined. The constant ΔK fatigue crack growth tests under programmed humidity cycle conditions were carried out to quantify the extent of the increase in fatigue crack growth rates due to the relative humidity. The obtained results are compared to the da/dN-ΔK relationships obtained from the constant amplitude dynamic load fatigue crack growth tests. It was found that the intrinsic fatigue crack growth rate increase with the relative humidity, but the extent of the increase was found to be considerably small compared to the growth rate difference between the laboratory air and vacuum conditions. The constant ΔK test at a high stress ratio under programmed humidity cycle conditions was effective for detecting the relatively small humidity effect on the fatigue crack growth rate.

Regular Papers

Microstructure

Structure and properties of interface between dissimilar materials(Review)

J.ECHIGOYA et al.

Recent work has been reviewed concerning the interphase interface between two materials which have different crystal structures and chemical compositions. We focus on the structure, and magnetic and mechanical properties of the interphase interface.

{001}〈210〉 texture development by two-stage cold rolling method in non-oriented electrical steel

M.TAKASHIMA et al.

The {001}〈210〉 texture, which is preferable for good magnetic properties in non-oriented electrical steel, is enhanced by the two-stage cold rolling method in which the intermediate annealing temperature is 640°C. The mechanism of {001}〈210〉 texture development by two-stage cold rolling method was investigated by the measurement of microtexture changes during annealing with EBSP (Electron Back Scattering Pattern). The intermediately annealed sheet, whose recrystallized fraction is 60%, mainly consists of 〈111〉//ND small equiaxed recrystallized grains and 〈110〉//RD elongated deformed grains. During final annealing, the growth of 〈111〉//ND recrystallized grains is suppressed and {001}〈210〉 grains grow consuming 〈111〉//ND recrystallized grains. This could be caused by the strain introduced by second cold rolling in 〈111〉// ND recrystallized grains. Consequently, {001}〈210〉 grains dominate the overall texture of the final annealed sheet.

Social and Environmental Engineering

140 years of blast furnace ironmaking in Japan (iron- and steelmaking on postcards)(Review)

M.M.WOLF

Iron- and steelmaking motives on stamps and postcards can stimulate the interest in historical metallurgy. In the present instance, such illustrative documentation brings about the commemoration of the 140th anniversary of blast furnace ironmaking in Japan.