

Japanese Aerospace Literature This month: *Titanium Alloys*

A95-16890 Texture formation during isothermal forging of TiAl-base alloys. H. INOUE, Y. YOSHIDA, and N. Inakazu (Osaka Prefecture Univ., Sakai, Japan), *Japan Institute of Light Metals*, Journal (ISSN 0451-5994), Vol. 44, No. 11, Nov. 1994, pp. 646-651. In Japanese. 17 Refs. Documents available from Aeroplus Dispatch.

The textures of the gamma phase formed by isothermal forging at 1373 K have been investigated in various TiAl-base alloys containing a small amount of the alpha2 phase using crystallite orientation distribution functions. The textures of 67 pct isothermally forged alloys consist mainly of the 100-line TD partial fiber component with a maximum peak in the vicinity of a 032-plane 100-line orientation. However, the degree of texture development is remarkably influenced by the compositions of the alloys. The addition of Mn as the third element and/or a decrease of the alpha2 content increase the intensity of the gamma textures. From the results of microstructural observations, it is obvious that the texture formation during isothermal forging is closely related to dynamic recrystallization as well as slip rotation through compressive deformation. The formation of the 032-plane 100-line texture may be explained by considering oriented nucleation and selective growth. (Author)

A95-15583 Effect of microstructure on small fatigue crack growth and the crack opening-closing behavior in Ti-6Al-4V alloy—Study on materials heat-treated in beta field. M. OKAZAKI and T. HIZUME (Nagaoka Univ. of Technology, Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 493, Oct. 1994, pp. 1238-1244. In Japanese. 15 Refs. Documents available from Aeroplus Dispatch.

The effect of microstructure on the small fatigue crack growth behavior was studied in Ti-6Al-4V alloy subjected to three kinds of heat treatments in beta field, in comparison with the long crack growth properties. The small crack opening-closing behavior relevant to microstructure was also investigated. The crack closing ratio exhibited a noteworthy behavior near crystallographic orientation boundaries: the ratio gradually increased as the crack tip approached the grain boundary and decreased after passing through. This behavior indicates that the change of the crack closure is one of the important factors which lead to the characteristic behavior of small crack growth near grain boundaries. It was shown from experimental evidence that the microstructural effect on the small crack growth rate and the difference in growth rate between small and long cracks are intrinsic, and not compensated only by the crack closure phenomenon. (Author)

A95-11515 On the correlation between microstructure and mechanical properties of titanium aluminide matrix composites. H. SUZUKI, Y. SHIRASUNA, A. NOZUE, and T. OKUBO (Sophia Univ., Tokyo, Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 492, Sept. 1994, pp. 1082-1086. In Japanese. 7 Refs. Documents available from Aeroplus Dispatch.

Titanium, aluminum, and fine SiC or Al₂O₃ powders were used to synthesize TiAl intermetallic-matrix composites by hot press reactive sintering. In the SiC reinforced composites, the exothermic heat during sintering caused a reaction between SiC powders and Ti, producing Ti-Si compounds. The compounds increased the hardness of the composites, and existed mainly between the Ti₃Al grain and the TiAl lamella. The fractured surface of the SiC reinforced composites showed much smaller cleavage than that found in the nonreinforced Ti-Al intermetallic. The change in size of microstructure was correlated with the size of fracture unit, using the result of microbeam X-ray analysis. (Author)

A95-11514 Mechanical properties of superplastically deformed Ti-15V-3Cr-3Sn-3Al alloys at room temperature. I. KUBOKI (Seiko Instruments, Inc., Chiba, Japan), Y. MOTOHASHI (Ibaraki Univ., Japan), and M. HIROHASHI (Chiba Univ., Japan), *Japan Institute of Light Metals*, Journal (ISSN 0451-5994), Vol. 44, No. 8, Aug. 1994, pp. 445-450. In Japanese. 11 Refs. Documents available from Aeroplus Dispatch.

Tensile and hardness tests were carried out at room temperature on superplastically deformed Ti-15V-3Cr-3Sn-3Al alloys. Aging at 753 K after superplastic deformation at 1023 K, above the beta-transus, yields faster hardening response and higher maximum hardness and tensile strength. The tensile strength as well as total elongation are increased by aging after solution treatment of the superplastically deformed specimens (i.e., the strength vs. elongation balance of the alloys is improved by the deformation and solution treatment and aging thereafter). This improvement might be caused by the precipitation of fine and acicular alpha-phases nucleated in thermally stabilized subgrains. (Author)

A94-35548 Study on X-ray stress measurement for titanium aluminide intermetallic compound. H. TABATA, T. SASAKI, Y. HIROSE (Kanazawa Univ., Kakuma, Japan), and Z. YAJIMA (Kanazawa Inst. of Technology, Nonoichi, Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 490, July 1994, pp. 812-818. In Japanese. 12 Refs. Documents available from Aeroplus Dispatch.

The study investigates X-ray stress measurement for a TiAl intermetallic compound of interest as a new structural material. The arc-melted Ti-48 mol pct Al alloy under consideration exhibited preferred orientation due to its lamellar structure. Two approaches are used to measure for the TiAl (311) plane using Cr-K-alpha characteristic radiation and a position-sensitive proportional counter: an oscillation method and a method utilizing only two 311 plane reflections that belong to one zone axis.

A94-34705 Effects of beta-STA heat treatment on initiation and propagation processes of microcracks in Ti-alloy. S. TANAKA, W. FUJISAKI, T. TERANISHI (Kyushu Sangyo Univ., Fukuoka, Japan), H. NISITANI (Kyushu Univ., Fukuoka, Japan), and M. HONDA (Tanaka Denko Co., Ltd., Osaka, Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 487, Apr. 1994, pp. 408-413. In Japanese. 14 Refs. Documents available from Aeroplus Dispatch.

To clarify the effects of beta-STA processing on fatigue behaviors of Ti-6Al-4V alloy, microcrack initiation and propagation processes were successively observed in a series of rotating bending fatigue tests of beta-STA material and annealed Ti-6Al-4V alloy. When the stress higher than a fatigue limit is repetitively applied to the specimen, microcracks appear from the alpha phase for the annealed material, while they appear along the fine acicular microstructure for the beta-STA material. When the stress corresponding to a fatigue limit is repetitively applied to the specimen, no microcrack appears in either of the materials. Accordingly, the fatigue limit is determined by the microcrack initiation limit. The fatigue limit of the beta-STA material becomes about 30 percent higher than that of the annealed material. It is inferred that beta-STA processing has little influence on resistance against the microcrack propagation but contributes to an increase in limiting stress for the microcrack initiation. (Author)

A94-23823 Temperature dependence of strength and fracture toughness in gamma-base titanium aluminides. R. GNANAMOORTHY, Y. MUTOH (Nagaoka Univ. of Technology, Japan), N. MASAHASHI, and Y. MIZUHARA (Nippon Steel Co., Kawasaki, Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 485, Feb. 1994, pp. 190-196. In Japanese. 20 Refs. Documents available from Aeroplus Dispatch.

Bending strength and fracture toughness tests were carried out on four kinds of gamma base titanium aluminides with different microstructures in the temperature range from room temperature to 1000 C. Both bending strength and fracture toughness at room temperature were highest for the one with lamellar structure and lowest for the one with equiaxed structure. Fracture toughness increased with an increase in temperature up to a critical temperature and then decreased. Chromium addition, which stabilizes ductile beta phase, significantly improved high temperature fracture toughness. The critical temperature at the maximum fracture toughness, which corresponds to recrystallization temperature, was around 800 C for binary and chromium added TiAl, while that for the niobium-added one was about 1000 C. (Author (revised))

A94-23822 Impact strength of beta-Ti alloy. K. OGAWA (Kyoto Univ., Japan), H. KOBAYASHI (Muroran Inst. of Technology, Japan), K. YOSHIDA, and F. SUGIYAMA (Kyoto Univ., Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 486, Mar. 1994, pp. 304-309. In Japanese. 13 Refs. Documents available from Aeroplus Dispatch.

Compressive strength of beta-titanium alloy (Ti-15V-3Cr-3Sn-3Al) was investigated in the temperature range 77-673 K and at strain rates from 10 exp -4 to 2 x 10 exp 3/s. The stress-strain relations are influenced by the change of temperature arising from the heat conversion of plastic work, while almost independent of the temperature and the strain rate histories. The thermal component of the stress can be uniquely determined by the Larson-Miller parameter, and the thermal component is a function of strain only. The thermally activated process concept gives a whole understanding of the present experimental results by taking account of the adiabatic heating effect at high strain rates of more than 100/s. (Author)

A94-23162 A stochastic model of fatigue crack propagation approximated by a successive random walk process. H. TOKUNO, T. OKADA (Kobe Univ., Japan), and T. NAKAGAWA (Ryukoku Univ., Otsu, Japan), *Japan Society of Materials Science*, Journal (ISSN 0514-5163), Vol. 43, No. 484, Jan. 1994, pp. 62-67. In Japanese. 12 Refs. Documents available from Aeroplus Dispatch.

In this study, crack propagation is regarded as a successive random walk process. Two Markovian models of crack growth described by the Fokker-Planck equation are introduced through Paris-Erdogan's law, and the crack length distribution at any fatigue cycle and the life distribution at any crack length are set up analytically with some approximations. The first model is expressed by the Fokker-Planck equation with constant coefficients, which can be calculated from the crack propagation data, and another model is introduced theoretically from the distribution of the coefficient of Paris-Erdogan's equation directly. These Fokker-Planck equations are analyzed by the Lax-Wendroff scheme, one of the finite-difference methods. As a result, the crack-length distribution in random stress sequences is evaluated successfully. (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)

A94-19699 Anisotropic fatigue crack propagation of Ti-6Al-4V alloy in 3 percent NaCl solution. K. TOKAJI (Gifu Univ., Japan), M. NAKAJIMA (Toyota College of Technology, Japan), T. Ogawa, (Gifu Univ., Japan), and T. Shimizu (Toyota College of Technology, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 482, Nov. 1993, pp. 1319-1325. In Japanese. 22 Refs. Documents available from Aeroplus Dispatch.

Fatigue crack propagation behavior has been investigated on a Ti-6Al-4V alloy in a 3 percent NaCl solution. Experiments were conducted on three different microstructures which were prepared with annealing at 705 C (AN705) and 850 C (AN850) and solution-treatment and aging (STA), and on two orientations. In T-L orientation for AN705 and AN850 and both orientations for STA, an abrupt increase in crack propagation rate took place at a certain DeltaK value, DeltaK (scc), which was strongly related to SCC under cyclic loading. Fractographic examination revealed that the fracture surfaces consisted of extensive cleavage when DeltaK is greater than DeltaK (scc). A considerable anisotropy in crack propagation behavior was observed for the annealed microstructures. Their crack paths in L-T orientation suddenly changed toward the rolling direction, suggesting the strong sensitivity to corrosion fatigue crack propagation in L-T orientation. The pole figures showed that the annealed microstructures had a transverse texture in which (0002)-planes were parallel to the rolling direction. This indicates that the largest susceptibility to aqueous NaCl is found for loads acting perpendicular to these planes, since cleavage-type fracture is known to be often observed on or near (0002)-planes. (Author (revised))

A94-18973 Ultrasonic fatigue behavior of Ti-6Al-4V alloy. H. ISHII (Shizuoka Univ., Hamamatsu, Japan), R. EBARA, Y. YAMADA (Mitsubishi Heavy Industries, Ltd., Hiroshima, Japan), and K. MINAKAWA (NKK Corp., Tokyo, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 481, Oct. 1993, pp. 1218-1223. In Japanese. 11 Refs. Documents available from Aeroplus Dispatch.

Ultrasonic fatigue testing has been used to ascertain the fatigue strength of Ti-6Al-4V at large numbers of cycles, after mill anneal, duplex anneal, and solution treatment-and-aging types of heat treatment. A fatigue limit appears to exist for this alloy at 10 exp 8 cycles; fatigue strength decreased at higher numbers of cycles.

A94-18970 Propagation of microscopic and macroscopic surface fatigue cracks under periodic overstressing in Ti-6Al-4V. K. FUJITA (Ube Technical College, Japan) and R. KOTERAZAWA (Tsukuba Univ., Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 481, Oct. 1993, pp. 1193-1199. In Japanese. 24 Refs. Documents available from Aeroplus Dispatch.

The fracture-surface morphology of the Ti-6Al-4V alloy subjected to surface fatigue crack propagation testing under conditions of periodic overstressing is one of zigzagging, reminiscent of large-acceleration macroscopic cracks in carbon steels and Al alloys. A good correlation is obtained for the tensile strength/Young's modulus ratio, which led to greater acceleration as it decreased.

A94-18969 Fatigue crack growth of Ti-6Al-4V alloy at elevated temperatures. T. OGAWA, Y. HAYASHI, K. TOKAJI, and M. HIROSE (Gifu Univ., Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 481, Oct. 1993, pp. 1186-1192. In Japanese. 11 Refs. Documents available from Aeroplus Dispatch.

The room temperature, 200, 400, and 500 C fatigue crack growth of the Ti-6Al-4V alloy was investigated with a view to the nucleation and morphology of secondary cracks. Crack growth rates at the higher temperatures were lower than at room temperature, with increasing stress intensity factor range, due to the nucleation of secondary cracks.

A94-18968 Fatigue strength and fatigue-crack initiation of Ti-6Al-4V alloy. S.-I. Nishida (Saga Univ., Honjo, Japan), C. URASHIMA (Nippon Steel Corp., Yawata Research and Development Lab., Kitakyushu, Japan), and N. TAKANO (Kanazawa Inst. of Technology, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 481, Oct. 1993, pp. 1179-1185. In Japanese. 8 Refs. Documents available from Aeroplus Dispatch.

An evaluation is conducted of the high cycle region fatigue strength of Ti-6Al-4V under rotating bending fatigue conditions; fractography is used to analyze test results. The fatigue crack initiation process is investigated via SEM in out-of-plane bending fatigue conditions.

A94-18967 Crack growth behavior of low cycle fatigue under single over-straining in Ti-6Al-4V alloy. Y. OCHI, A. ISHII, S. SASAKI, and I. OHDACHI (Univ. of Electro-Communications, Chofu, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 481, Oct. 1993, pp. 1172-1178. In Japanese. 28 Refs. Documents available from Aeroplus Dispatch.

An investigation is conducted of low cycle fatigue deformation and surface crack propagation, in constant strain amplitude and single overstraining conditions, for alpha/beta-rolled Ti-6Al-4V plates with conventionally annealed equiaxial microstructure. The two types of overstraining were tension-only and tension-compression.

A94-18965 Influence of heat treatment on low-cycle fatigue in Ti-6Al-4V alloy. K. HATANAKA, J. OHGI, and F. UENO (Yamaguchi Univ., Ube, Japan), *Japan Society of Materials Science, Journal* (ISSN 0514-5163), Vol. 42, No. 481, Oct. 1993, pp. 1153-1159. In Japanese. 23 Refs. Documents available from Aeroplus Dispatch.

Specimens of Ti-6Al-4V that were annealed at 750 C have been solution-treated and aged at 520 and 660 C to create conditions designated 7N, 5T, and 6T. These specimens have been subjected to low-cycle fatigue in axial strain-controlled conditions. The most favorable stress-strain response was obtained in the 5T material, followed by 6T and 7N. Resistance to surface-crack extension was also greatest in the cases of 5T and 6T specimens.

A94-16470 Effect of third elements on high-temperature strength of TiAl base alloys. K. HASHIMOTO, M. NOBUKI, H. DOI, T. KIMURA, T. TSUJIMOTO, and M. NAKAMURA (National Research Inst. for Metals, Tokyo, Japan), *Japan Institute of Metals, Journal* (ISSN 0021-4876), Vol. 57, No. 8, Aug. 1993, pp. 898-904. In Japanese. 10 Refs. Documents available from Aeroplus Dispatch.

After the heat-treatment of 1473 K-10.8 ks, the yield stress of TiAl (gamma) base alloys, Ti-50 mol pct Al, Ti-(50-C) mol. pct Al-C mol pct X, and Al-(50-C) mol pct Ti-C mol pct X, was examined by the compression test as a function of temperature (295-1273 K) and the amount, C(0.5-2.0), of third elements, X(Cr, Ga, Zr, Nb, Sb, Hf, Pd, Pt, Ta). Microhardnesses of gamma in the alloys were measured at room temperature to confirm solid solution hardening. The microstructures were examined using OM, SEM, EPMA and XRD. The results obtained were examined with regression analysis and compared with the microstructures. The microhardness increased with the amount of additives. The increase was remarkable with increasing difference in atomic radius between Ti or Al and X atoms. In the temperature range of 295-1073 K, the yield stress is in proportion to the microhardness and influenced by the amount of Ti3Al phase and the grain size of gamma phase. At 1273 K, the effect of the microstructure on the yield stress decreased and the effect of solid solution hardening became prominent. (Author (revised))

A94-11959 Oxidation resistance of TiAl improved by CoCrAl and CoCrAlY coating. S. TANIGUCHI, N. ASANUMA, T. SHIBATA (Osaka Univ., Suita, Japan), F. WANG, H. LOU, and W. WU (Chinese Academy of Sciences, Inst. of Corrosion and Protection of Metals, Shenyang, China), *Japan Institute of Metals, Journal* (ISSN 0021-4876), Vol. 57, No. 7, July 1993, pp. 781-789. In Japanese. 26 Refs. Documents available from Aeroplus Dispatch.

Oxidation resistance of TiAl coupons coated with Co-30Cr-4Al and Co-30Cr-4Al-0.2Y (mass percent) coatings has been assessed by isothermal oxidation test in a temperature range 1100 to 1400 K and by cyclic oxidation test at 1200 K. The coating, consisting of very fine grains, was prepared by magnetron sputtering with resulting thicknesses of 30-40 microns. Both the coatings are, very effective to suppress the oxidation below 1300 K. This effect is attributable to the formation of alpha-alumina scales. However, after long oxidation periods, the oxidation manner changes from parabolic to accelerated oxidation. This acceleration is explained in terms of local growth of rutile on the scale. Relatively large voids are formed at the scale/coating interface, within the coating, and the coating/substrate interface. The addition of Y to the coating results in the flat scales with no voids at the scale/coating interface, though the oxidation rate slightly increases and the recrystallization of the coating is delayed. (Author (revised))

A93-54125 Influence of minor elements on oxidation behavior of TiAl intermetallic compound. M. KUMAGAI, K. SHIBUE, and M.-S. KIM (Sumitomo Light Metal Industries, Ltd., Technical Research Labs., Nagoya, Japan), *Japan Institute of Metals, Journal* (ISSN 0021-4876), Vol. 57, No. 6, June 1993, pp. 721-725. 10 Refs. Documents available from Aeroplus Dispatch.

The influence of chlorine, sodium, and oxygen in TiAl on its oxidation behavior was studied by using reactive-sintered Ti-33.5 mass pct Al-2.5 mass pct Mn made from various raw powders. As the chlorine content in the reactive-sintered TiAl-Mn increases, the mass gain after the oxidation test at 1223 K for 86.4 ks decreases. the TiAl-Mn containing more than 500 ppm chlorine has excellent oxidation resistance owing to the protective Al2O3 film formed on the surface at an early stage of oxidation. Chlorine in the TiAl-Mn exists as NaCl particles which are introduced from the Ti powder produced by the Hunter method. Moreover, halogens such as fluorine and bromine were found to improve the oxidation resistance of TiAl-Mn. (Author (revised))

A93-54124 Effect of hydrogen charge on Charpy impact energy in Ti-15V-3Cr-3Al-3Sn and Ti-13V-11Cr-3Al alloy. K. NAKASA, H. SATOH, and H. NISHIYAMA (Hiroshima Univ., Higashihiroshima, Japan), *Japan Institute of Metals, Journal* (ISSN 0021-4876), Vol. 57, No. 6, June 1993, pp. 637-644. 18 Refs. Documents available from Aeroplus Dispatch.

Charpy impact tests were carried out on the Ti-15V-3Cr-3Al-3Sn (15-3-3-3) and Ti-13V-11Cr-3Al (13-11-3) alloys which were hydrogen-charged in sulfuric acid solution with a concentration of 0.5 kmol/cu m under a charging current density of 1000 A/sq m. Hydrogen charging resulted in a decrease in Charpy impact energy for the as-solution treated 15-3-3-3 alloy at temperatures lower than 300 K, and for the aged alloy at temperatures lower than 700 K. For the aged 13-11-3 alloy, the impact energy decreased slightly by hydrogen charging at all testing temperatures. The aged 15-3-3-3 alloy was higher in hydrogen concentration C(H) than the as-solution treated one and the aged 13-11-3 alloy, and the alloys did not show any change in C(H) by heating up to 700 K. The hydrogen charging promoted the cleavage fracture of the as-solution treated 15-3-3-3 alloy and the aged 13-11-3 alloy, and the quasi-cleavage fracture of the aged 15-3-3-3 alloy. (Author (revised))