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NEW LIMITATION CHANGE

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AUTHORITY

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PHASE TRANSFORMATIONS

A comparison of the phase relationships and transformations in three commercial titanium alloys recently has been completed in an investigation at Boeing.[1] Figure 1 summarizes the occurrence of the phases found in the Ti-4Al-3Mo-1V, Ti-6Al-4V, and Ti-8Al-1Mo-1V alloys after quenching from various solution temperatures. Two types of martensite were found to exist; one is either a face-centered-cubic or a face-centered-tetragonal structure, designated α', while the other is a hexagonal-close-packed structure, designated α''. These structures are transformation products from the beta phase and coexist with the other phases shown in Figure 1 to make up the overall structure observed at room temperature after quenching from the solution temperatures indicated.

The tempering or aging of the products formed on quenching can result in the following decompositions depending on composition and aging conditions. The omega phase formed from the decomposition of the beta phase in both the Ti-4Al-3Mo-1V and Ti-8Al-1Mo-1V alloys but was not observed as a result of aging the Ti-6Al-4V alloy. The alpha phase precipitated from the beta phase in all three alloys. The α' martensite reverted to the beta phase on aging and, in turn, the beta phase precipitated alpha phase. The possibility of alpha phase precipitation from α' prior to its reversion to beta was reported. The transformation of the α'' martensite was reported to be simply the precipitation of beta phase within the α'' platelets, the composition of which approaches the equilibrium alpha composition as the reaction continues. Combinations of these reactions undoubtedly occur during the commercial heat treatment of the Ti-4Al-3Mo-1V and Ti-6Al-4V alloys. Since the Ti-8Al-1Mo-1V alloy is not usually heat treated, the phase relationships reported from above about 1600 F may not be observed in structures produced commercially, depending on the cooling rate used.

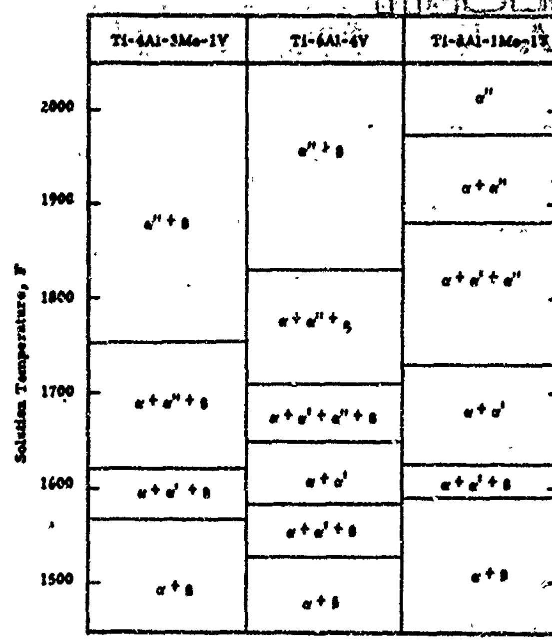

FIGURE 1. EQUILIBRIUM ALPHA (α), BETA (β), AND TRANSFORMATION PHASES (α' AND α'') PRESENT AFTER QUENCHING FROM SOLUTION TEMPERATURES INDICATED[1]

ALLOY DEVELOPMENT

Progress by Crucible Steel Company on Phase I of a manufacturing development program for their Beta III alloy, Ti-4.5Sn-6.0Zr-11.5Mo, was reported recently.[2] This alloy has many characteristics of those shown by the Ti-6Sn-12Mo, Beta II alloy studied by Crucible under a previous Air Force contract.[3] One major advantage of the Beta III composition is the improved freedom from molybdenum segregation on melting as a result of introducing molybdenum in the form of a zirconium-molybdenum alloy. Specimens cut from heat-treated plate of the Beta III developed up to 190 ksi tensile yield strength with 7 to 10 percent elongation. On cold-rolled, solution-treated and aged sheet, tensile strengths of over 200 ksi with 8 percent elongation were obtained.

Elevated-temperature properties of the alloy are attractive and the cold workability of this grade (cold rollability, bend ductility, and cupability) is outstanding among titanium alloys. Phase II of the study is the scaleup and study of 4000- and 8000-pound ingots.

APPLICATIONS

The Navy's program on weldable, heavy-plate titanium alloys for use in pressure hulls includes two candidate compositions, Ti-6Al-2Cb-1Ta-0.8Mo and Ti-6Al-4V ELI. One of these may possibly be used in two programs that are soon to be implemented: The Deep Submergence Rescue Vehicle (DSRV) and the Deep Submergence Search Vehicle (DSSV) programs. The Navy evaluation of the Ti-6Al-2Cb-1Ta-0.8Mo composition is somewhat ahead of that of the Ti-6Al-4V ELI grade. The rationales of selecting

titanium alloys from among the great number of titanium alloys examined were described in a recent presentation.(4)

In a paper describing titanium for desalination plants and other hot-seawater applications, the advantages and possible problem areas for titanium are discussed.(5) The desalination plant on St. Croix, Virgin Islands, which uses 432,000 feet of titanium tubing supplied by the Titanium Division of Harvey Aluminum, has been a notably successful test bed. While erosion, corrosion, or general wasting of material is definitely not a problem, crevice corrosion is still considered a potential problem. Pitting corrosion in crevice locations above 250 F is not unknown. However, the Titanium Metals Corporation of America has found that alloys such as Ti-0.2Pd, Ti-2Mo, and Ti-2Ni show improved resistance to this form of attack. While the author of the paper concluded that the present market price of titanium tubing does not favor its selection immediately for desalination plants, he points out that the time is coming when price will no longer be the prohibiting factor. In addition, there are already certain severe applications involving seawater where the corrosion-resistant features of titanium cannot be met by traditional materials. This is illustrated by the corrosion data given in Table 1.

Other seawater applications for titanium are also receiving the attention of military interests. These include the use of Ti-6Al-4V alloy pressure bottles for service as variable ballast equipment in "Alvin", the Deep Submersible Research Vehicle and a Ti-6Al-4V alloy boom and upper mast of the America's Cup winner, Intrepid.(6)

SURFACE TREATMENTS

In a study conducted at the IBM Systems Development Laboratory, three types of surface treatments for possible improvement of the impact-fatigue characteristics of Ti-6Al-4V alloy machine parts were examined.(7) Abrasive and impact wear of the parts also were important considerations. Nitrided and oxidized surfaces were evaluated as examples of gaseous-diffusion coatings. A thin, chromium-enriched surface layer was evaluated as an example of a diffused-metal coating, and a nitrided diffused-chromium coating was examined as one possible modification of this surface treatment. Peak hardnesses and depth of hard surface layers for the heat-treated Ti-6Al-4V specimens are given together with the test data in Table 2. While the unique features of parameters such as impact wear and impact-fatigue may not be applicable to many applications apart from business-machine parts, the relative effectiveness of coatings is apparent. The authors conclude that achievement of simultaneous optimization of impact-fatigue and wear characteristics in Ti-6Al-4V by surface treatment is improbable.

In a paper presented by Kostman of TMCA, numerous test data were presented to show the effect of various lubricants and coatings on the wear char-

TABLE 1. RESULTS OF SEAWATER CORROSION TESTS(5)

(Tube Exchanger, International Salt Company)

Materials(a)	Weight Loss, percent
Alloy 755, 90-10 cupro-nickel	Dissolved
Alloy 713, 80-20 cupro-nickel	44.0
Alloy 807, 70-30 cupro-nickel	34.2
Alloy 702, 70-30 cupro-nickel	26.9-27.4
Monel	11.2-12.3
Ti-55A, titanium (unalloyed)	None

(a) Test Specimen: 1 by 4-inch test section in 5/8-inch-diameter tubing. Tubing roller-expanded into tube sheet with standard practice. Test Conditions: Salt slurry 20 vol%, at 226 F brine velocity, with 200-day test period.

TABLE 2. TYPICAL PROPERTIES OF SURFACE-TREATED, SOLUTION HEAT-TREATED AND AGED Ti-6Al-4V SPECIMENS AFTER SPECIAL TESTING(7)

Surface Treatment	Depth of Altered Surface Layer, in.	Peak Hardness of Surface Layer, Khn	Impact-Fatigue Strength (10^7 cycles, $K_t = 2.06$), ksi	Impact Wear, (10^6 cycles, 20 ksi stress), 10^{-3} in.	Abrasive Wear, (Hertz contact stress = 20 ksi), 10^{-4} g in 20 min	Deficiency in Characteristic
None	--	450	73	0.52	0.64	Abrasive wear
Sandblasted	--	450	94	0.17	0.64	Abrasive wear
Nitride	0.004	1650	45	2.08	0.23	Impact-fatigue and impact wear
Oxide	0.004	950	35	1.68	0.30	Impact-fatigue and impact wear
Diffused chromium	0.006	660	57	0.30	0.45	Abrasive wear
Diffused chromium plus pickle	0.006	660	94	0.95	0.32	Abrasive wear and impact wear
Diffused chromium plus nitride	0.012	1600	40	0.22	0.70	Impact-fatigue, impact wear, and abrasive wear

acteristics of Ti-6Al-4V alloy (annealed).[8] Representative test data are given in Table 3. Among the conclusions reached in this study were:

(1) Liquid lubricants are ineffective on bare surfaces, while bonded solid-film lubricants (MoS_2) applied to prepared surfaces are very effective

(2) Vapor blasting is a very effective surface preparation for solid-film lubricants

(3) Combinations of conversion coating plus surface roughening offer optimum surface preparation for solid films

(4) Oxide coatings produced in molten lithium carbonate lubricated with liquids can provide long wear life at high loads, although fatigue strength is diminished by such coatings

(5) Electroplated metals and sprayed ceramic coatings (WC, TiO_2, Cr_2O_3) can be effective for wear protection, but tend to be of limited usefulness due to lack of adhesion or chip and spall tendencies, respectively

(6) Flame-sprayed coatings of molybdenum give excellent wear life against steel.

TABLE 3. TYPICAL WEAR DATA OBTAINED WITH SURFACE AND/OR LUBRICATED ANNEALED Ti-6Al-4V ALLOY[8]

			Test Conditions			
Surface Treatment	Lubricant	Average Wear Rate,[a] in./ft of sliding	Time, min	Load, lb	Speed, ft/min	Minimum Contact Pressure, ksi
Untreated	Halocarbon 11-14	1.6×10^{-7}	140	10	26	--
Untreated	Bonded MoS_2	1.5×10^{-6}	4	210	26	40
Vapor Blasted, 42 to 44 µ in., rms	Bonded MoS_2	2.3×10^{-8}	2,920	630	26	25
Vapor Blasted, Li_2CO_3 oxidized (3 hr at 1475 F), 46 to 48 µ in., rms	Bonded MoS_2	2.3×10^{-8}	4,900	630	26	21
Chromium Plated, 1 to 2 mils	SAE-30	Plate failure	173 (to failure)	210	26	2.2
Electroless Nickel-Plated, 1 to 2 mils	SAE-30	Plate failure	183 (to failure)	210	26	6.8
Molybdenum Spray-Coat, 4 mil[b]	SAE-30	Slight wear	11,700	630	26	10

(a) Wear testing accomplished using an Alpha LFW-1 modified machine. Specimen sets consisted of a cylindrical bearing ring and a rectangular block.
(b) Test was against a steel block.

CORRECTION TO AUGUST 24 REVIEW

In the August 24 Review of Recent Developments - Titanium and Titanium Alloys - there was a temperature error on Page 2, Column 1 of the second complete paragraph (Reference 3), i.e., the noses of the TTT curves for all alloys were found to lie between 600 and 650 C (instead of F).[9]

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R. W. Endebrock, Editor