AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

ARP 982 A

Issued 11-1-67
Revised 11-15-71

MINIMIZING STRESS-CORROSION IN WROUGHT TITANIUM ALLOY PRODUCTS

1. PURPOSE: Primarily to provide the aerospace industry with recommendations concerning minimizing of stress-corrosion cracking in wrought titanium alloy products.

1.1 The detailed recommendations are based on laboratory experience and reflect those design practices and fabrication procedures which should avoid in-service stress-corrosion cracking of wrought titanium alloy products.

1.2 It must be emphasized that while stress-corrosion cracking in service has been observed, the chemical environmental conditions have in all instances been unusual and, although it is possible to produce stress-corrosion cracking of titanium alloys under more common conditions as discussed in these recommendations, there have been few, if any, failures in such environments.

2. GENERAL: All metal alloy systems are subject to stress-corrosion cracking under appropriate conditions; titanium alloys are no exception to this rule. Stress-corrosion failures of wrought titanium alloy parts are possible if the following combination of factors is met:

a) Presence of a sustained high surface tensile stress developed as a result of assembly stresses and/or residual stresses due to heat treatment or forming (or plane strain produced by the tensile stress concentration at the root of a pre-existing crack), and

b) Presence of environmental conditions specific to the material under consideration.

2.1 There are several types of environments in which stress cracking of titanium alloy parts may occur. These environments and the alloys currently known to be susceptible to cracking in each type are:

a) Environments in which both initiation and propagation may occur at low stress concentration factors; that is, cracking of smooth machined components may occur at sufficiently high applied stress.

a-1. Alkali halide salts (and halide salts of some other metals) above 500 F (260 C) (oxygen and water vapor are contributing factors). In general, all commercially available titanium alloys are believed to be susceptible to hot salt cracking. Typical alloy compositions which have evidenced susceptibility are listed below:

Ti-5Al-2.5Sn	Ti-3Al-11Cr-13V
Ti-2.25Al-11Sn-5Zr-1Mo-0.25Si	Ti-6Al-2Sn-4Zr-2Mo
Ti-6Al-4V	Ti-5Al-6Sn-2Zr-1Mo-0.25Si
Ti-6Al-6V-2Sn	Ti-8Al-1Mo-1V

a-2 Silver, cadmium, and mercury have been found to promote cracking of the following alloys:

Ti-6Al-4V (in Ag, Hg, or Cd)	Ti-5Al-2.5Sn (in Ag)
Ti-6Al-6V-2Sn (in Ag or Cd)	Ti-8Mn (in Cd)
Ti-7Al-4Mo (in Ag)	Ti-3Al-11Cr-13V (in Hg)
Ti-8Al-1Mo-1V (in Ag)	Commercially Pure (in Hg)

 Printed in U.S.A.

Temperature and stress limits for cracking in these environments have not been firmly established and caution should therefore be exercised.

a-3. Methyl alcohol. All titanium alloys are believed to be susceptible; cracking may occur at 70 F (21 C) but temperature limits have not been established. Probability of cracking is increased by the presence of alkali halide salts, HCl, or H_2SO_4. Cracking is inhibited by the presence of 1% or greater H_2O.

a-4. Nitrogen tetroxide (N_2O_4). Titanium 6Al-4V tankage holding N_2O_4 with no measurable amounts of NO in a temperature range of 85 - 165 F (29.4 - 73.9 C) has failed by stress corrosion. Other titanium alloys are also susceptible. Cracking is inhibited by presence of 0.4 to 0.8% NO in propellent grade N_2O_4.

b) Environments in which brittle cracking may occur under high stress concentrations; that is, a pre-existing crack may propagate under applied stress, provided component geometry is such as to produce plane strain conditions. All titanium alloys are believed to be susceptible in some degree, with the exception of low-oxygen, low-iron titanium such as the commercially pure alloys used in chemical plants. The following environments may produce this susceptibility:

b-1. Aqueous solutions of alkali halides; the lower limit of halide salt concentration has not been firmly established and caution should therefore be exerted even with pure water.

b-2. Many organic liquids, notably anhydrous methanol and halogenated hydrocarbons, also produce susceptibility to some degree.

b-3. Mercury and cadmium.

2.2 Performance Under Service Conditions: Severe stress corrosion cracking of titanium alloys has been encountered in highly stressed pressure vessels containing methyl alcohol or containing N_2O_4 free of NO. Also, small cracks have been seen in wrought titanium components exposed to halide salts during heat treatment. With these exceptions, stress-corrosion cracking has rarely, if ever, occurred under service conditions. The alloys Ti-6Al-4V ELI and Ti-6Al-2Sn-4Zr-2Mo in particular exhibit low susceptibility. While laboratory testing showing the possibility of stress-corrosion cracking indicates a need for caution, service experience with titanium alloys has been extremely good compared with other structural materials.

3. RECOMMENDATIONS:

3.1 Environmental Compatibility: Alloys should be selected which offer adequate resistance to stress-corrosion for the environment in which they are to be used. Alloys with intermediate resistance are Ti-6Al-4V, Ti-6Al-6V-2Sn, and Ti-13V-11Cr-3Al. Ti-4Al-3Mo-1V is one of the most resistant alloys. Alloys that are highly resistant to seawater crack propagation under plane strain conditions include Ti-2Al-4Mo-4Zr, Ti-4Al-3Mo-1V, Ti-6Al-2Cb-1Ta-1Mo, and Ti-6Al-4V ELI.

Addition of small amounts of water to methyl alcohol and either water or nitrogen oxide (NO) to N_2O_4 tends to inhibit stress-corrosion by these environments.

3.2 Processing and Heat Treatments: Studies now in progress have indicated that heat treatment and processing variables play a major role in sensitizing titanium alloys to stress-corrosion cracking. Beta processing followed by normal heat treatments, or normal processing plus beta heat treatments reduces or eliminates sensitivity to stress-corrosion cracking of most alloys in aqueous environments. However, beta structures are often weaker and less ductile. The effectiveness of these treatments varies with the alloy grades and does not necessarily apply to other forms of stress-corrosion. For example, beta processing or heat treatment generally increases the sensitivity of alloys to hot salt corrosion while imparting resistance to room temperature aqueous stress-corrosion cracking.