SAE INTERNATIONAL

AEROSPACE RECOMMENDED PRACTICE

ARP982™ REV. D

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Superseding ARP982C

Minimizing Stress-Corrosion Cracking in Wrought Titanium Alloy Products

RATIONALE

ARP982D has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE

Primarily to provide recommendations concerning minimizing 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 obviate 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. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP1795 Stress Corrosion of Titanium Alloys, Effect of Cleaning Agents on Aircraft Engine Materials

3. 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 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 (media, temperature, stress, time) specific to the material under consideration.

3.1 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.

1. Alkali halide salts (and halide salts of some other metal) 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.

2. Silver, cadmium, and mercury have been found to promote cracking in titanium alloys; temperature (even room) and stress limits for cracking have not been firmly established and caution should therefore be exercised.

3. Methyl alcohol (methanol). Susceptibility of titanium to SCC in methanol is the greatest at room temperature 68 °F (20 °C) with increasing temperatures resulting in decreased SCC susceptibility. Time to cracking is decreased by the presence of halides, acidification, or presence of strong oxidizers. A minimum water content of 3 wt. % is sufficient to prevent SCC for most titanium alloys during sustained exposure to methanol solutions.

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 86 to 167 °F (30 to 75 °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 propellant grade N_2O_4.

5. Red fuming nitric acid caused one of the early stress-corrosion problems encountered with titanium. It has been determined that red fuming nitric acid with less than 1.5 % water and less than 10 to 20 % NO_2 will aggressively attack the metal and result in a pyrophoric reaction.

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. The following environments may produce this susceptibility:

1. Aqueous solutions of alkali halides; the lower limit of halide salt concentration has not been firmly established and caution, even in pure water, should be exercised.

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

3. Mercury and cadmium.

3.2 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.

4. RECOMMENDATIONS

4.1 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. Although not commercially produced anymore, 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-4Al-3Mo-1V, Ti-6Al-2Cb-1Ta-1Mo, and Ti-6Al-4V ELI.

4.1.1 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.

4.2 Processing and Heat Treatments

Studies 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 often have lower tensile properties with reduced ductility. 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.

4.3 Design Stresses

Threshold stresses that develop hot salt stress-corrosion cracking are often determined in laboratory testing of simple specimens with salt coatings; other conditions not necessarily simulating operations may be used as a guide in limiting maximum tensile stresses. However, experience has shown, at least in the instance of aircraft turbine engines, that these laboratory derived stresses are conservative when compared with stresses found to be safe in service. There is no background of experience relating to the propagation of brittle cracks under the influence of water or saline solutions but, on general principles, high stress concentration factors should be avoided. Depending on circumstances, this may demand that the fatigue endurance limit be used as the design limit for cyclic stresses. When high sustained loads at high stress concentration factors are unavoidable, an alloy with low susceptibility to propagation of brittle cracks in the presence of aqueous solutions should be used. Such alloys include Ti-6Al-2Cb-1Ta-1Mo and Ti-6Al-4V-ELI.

4.4 Surface Compressive Stresses

The above-mentioned design limitations are generally raised when surface compressive stresses are introduced, such as by shot peening.

4.5 Protective Coatings

Research has shown that continuous nonporous coatings can prevent hot salt stress-corrosion cracking. However the adverse effects on engineering properties and the problems of maintaining a continuous nonporous coating discourage any commercial usage.