

Evaluation of Titanium 475 Alloy for Use in Oil and Gas Environments

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ABSTRACT

A new titanium alloy, TIMETAL® 475 (Ti-475), which was developed for use in aggressive geothermal fields as a casing material, has been tested for use in typical oil and gas environments. The alloy composition, Ti-0.4Ni-3.75Mo-0.75Zr, provides excellent corrosion resistance in geothermal brines which are low pH and high in chlorides. For oil and gas applications, the additional effects of H₂S and CO₂ on the alloy must be considered. To this end, the alloy was subjected to the NACE TM-0177 Level VII exposure test. For the geothermal application, the alloy is prepared in the Solution Treated and Aged (STA) condition with a typical titanium bimodal microstructure. For use in oil and gas, the alloy is prepared in the Beta Annealed condition. The beta annealed condition is required for large components such as titanium stress joints where superior fatigue properties are required. This paper reviews the mechanical properties and corrosion evaluation of the Ti-475 alloy in the beta annealed condition as compared to the STA condition.

Key words: titanium alloy, oil and gas, beta, stress corrosion cracking, materials performance, sulfide stress cracking

INTRODUCTION

ASTM Grade 29 titanium alloy (UNS R56404) has been traditionally used for oil and gas stress joints (TSJ) [1]. However, given the general difficulty of processing this type of alloy in the beta quenched condition and more recently the exorbitant increase in alloying costs due to the ruthenium, a new solution is required if titanium is to be considered for future applications. This 475 alloy was developed to meet geothermal requirements to replace Grade 29 seamless casing. The essential material properties of Grade 29 in bulk and welded condition as used for titanium stress joints were reported by Shutz et al. [2].

Effects of galvanic corrosion in the TSJ application were reported by Shutz [3]. More specific requirements for corrosion fatigue and fatigue crack growth rate were presented by Rombado et al. [4,5]. Hence the mechanical and corrosion requirements for TSJ's are well known and can be used to qualify the new alloy.

Macdonald and Grauman [6,7] showed that this alloy has good corrosion resistance in hot sour geothermal brines in the STA condition, almost equivalent to Grade 29. In related work, Bente et al. [8] showed excellent resistance to high temperature hydrogen attack at 350°C, expected in supercritical steam geothermal wells where local condensation is expected during thermal cycling. Thorhallson et al. [9] showed that Ti-475 resists attack inflowing condensing steam at 350°C with H₂S, CO₂ and chlorides. These studies indicated that is very resistant to aggressive environments, far exceeding the levels expected in oil and gas applications.

During development, it was determined that roughly equivalent mechanical properties to Grade 29 were achieved using the STA treatment as reported by MacDonald and Gram [10]. For the TSJ oil and gas application, the mechanical and corrosion properties in the beta heat treated condition, which typically has high fracture toughness, needs to be evaluated. This paper reports on progress to date with further work planned to investigate the fatigue and fracture properties of the alloy in the beta annealed condition.

EXPERIMENTAL PROCEDURE

Samples of Ti-475 material were sourced from industrial scale seamless 10 3/4" diameter extrusions. Approximately 24" inch long rings were heat treated at temperature then sectioned. For tensile properties, samples were directly machined from the rings. For metallography and corrosion testing, sections in the as-extruded condition were hot rolled to strip, then heat treated to the beta annealed and the STA condition under three cooling conditions, a fast laboratory quench and a delayed quench to simulate manufacturing and an air cool. Metallographic specimens were prepared using conventional titanium polishing and etching techniques then examined optically. The samples were then cleaned, and u-bends were made. The U-bend imparts approximately 20% cold work in the outer fibers [11]. The U-bend samples were tested according to TM-0177 Method C at NACE Level VII conditions. Upon return, the samples were visually examined for any signs of pits or cracking at 10X.

RESULTS

Microstructure

The microstructures of the STA and beta heat treatments are shown in Figures. 1 and 2, respectively. The STA structure develops a bimodal microstructure with elongated primary alpha and a fine transformation product. The quench delay allows the primary alpha to coarsen. In the air-cooled condition, the secondary alpha is coarser, and the primary alpha fraction is higher, increasing the overall primary alpha content. The mechanical properties associated with these structures are consistent with the decreasing cooling rate and coarser structure.

In the high temperature beta+150°F condition, there is not a significant difference in the microstructure after water quench, quench after delay or after an air cool, yet there is a mechanical property difference. As expected, improved properties result at the lower annealing temperatures of beta+50°F as a result of a smaller beta grain size.

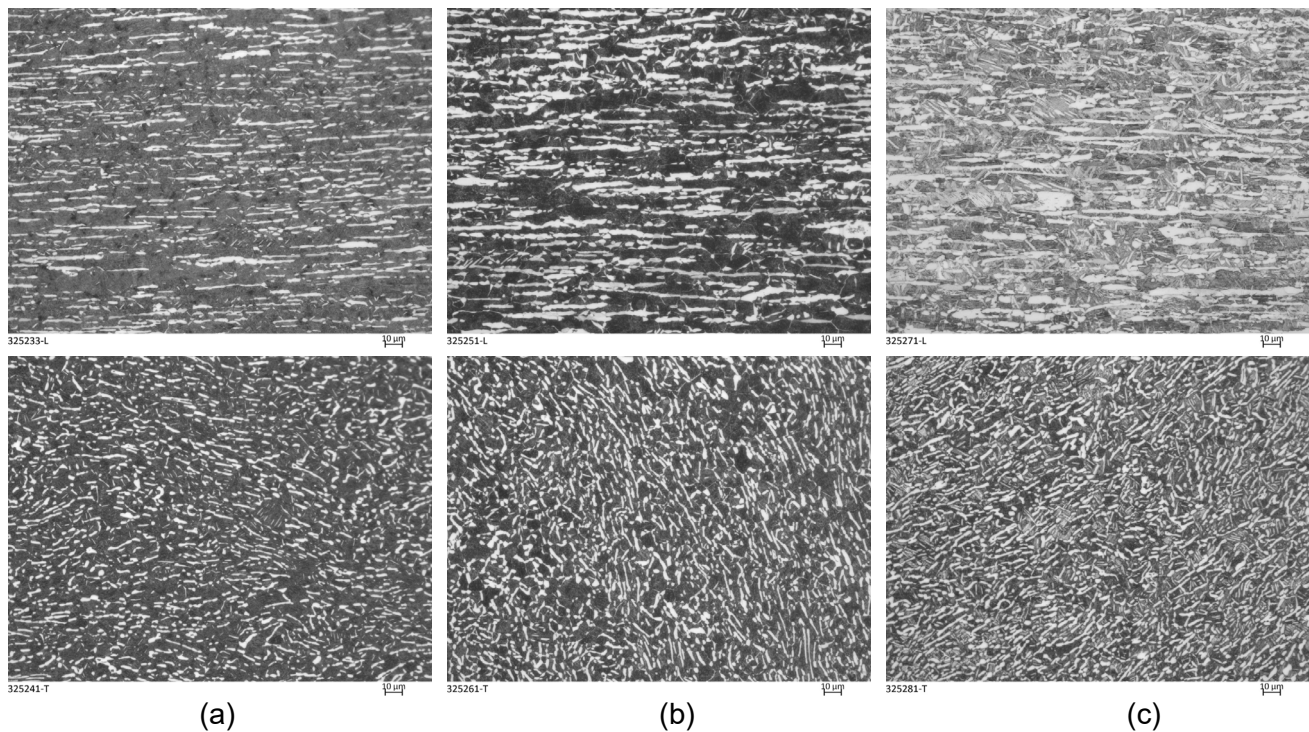


Figure 1: Influence of cooling rate on the microstructure of Ti-475 treated in the STA condition. Top row is longitudinal, bottom is transverse. (a) Water quenched and aged, YS = 130 ksi, %EL = 16%, HRC = 34, (b) Delayed water quench, YS = 124 ksi, EL = 17%, HRC=33, (c) Air cool, YS = 95 ksi, EL=25%, HRB = 96.

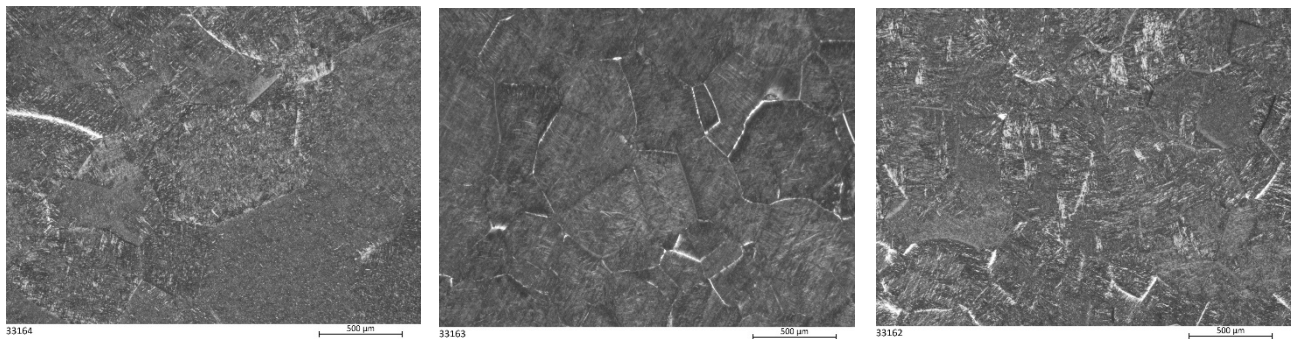


Figure 2: Influence of cooling rate on the microstructure of Ti-475 treated in the Beta annealed condition. (a) Water quenched from beta+150°F, YS = 145 ksi, %EL = 3%, HRC = 33, (b) Delayed water quench from beta+50°F and aged, YS = 125 ksi, EL = 8%, (c) Air cool from beta +50°F, YS = 102 ksi, EL=20%