# Cast Transage 175 Titanium Alloy for Durability Critical Structural Components

F.A. Crossley*
*Lockheed Missiles & Space Company, Sunnyvale, California*
and
W.J. Barice†
*Precision Castparts Corporation, Portland, Oregon*

**Limited fatigue data are reported for cast-to-size plus hot isostatically processed tensile test bars of the martensitic Transage 175 alloy (Ti-2.5Al-13V-7Sn-2Zr). The testing was done to assess the potential of the alloy for castings of rotating engine components such as impellers and fan rotors. Test conditions imposed were smooth-bar, low-cycle, axial ($A=1$, $R=0$) fatigue at 250 and 500°F (121 and 260°C), and smooth- and notched- ($K_t=3$) bar, high-cycle, axial ($A=\infty$, $R=-1.0$) fatigue at 250°F. Tension test properties from 76 to 800°F (24 to 427°C) are also reported. The results show excellent promise.**

## Nomenclature

| | |
|---|---|
| $A$ | = ratio of alternating stress (or strain) to mean stress (or strain) in load- (or strain-) controlled fatigue testing |
| AC | = air-cooled |
| CTS | = cast-to-size tension test specimens with 0.25-in.-diam (6.4-mm-diam) gage section |
| HCF | = high-cycle fatigue, $10^6$ cycles or more of load |
| HIP | = hot isostatically processed or hot isostatic processing |
| $K_t$ | = stress concentration factor |
| LCF | = low-cycle fatigue, $10^5$ or fewer cycles of load |
| $R$ | = ratio of minimum to maximum stress in load-controlled fatigue testing; and the ratio of minimum to maximum strain in strain-controlled fatigue testing |
| STA | = solution heat-treated and age-hardened |
| T175 | = Transage 175 alloy (titanium-2.5 wt.% aluminum-13 wt.% vanadium-7 wt.% tin-2 wt.% zirconium) |

## Introduction

FOR several years, efforts to reduce the cost of titanium structural components have focused on means to reduce buy-to-fly weight ratio and the amount of machining required to produce the net shape. Three means that have received a good deal of attention are 1) net shape or near net shape isothermal forging, 2) powder, and 3) casting. The most used titanium alloy, Ti-6Al-4V, has such a high isothermal forging temperature that the net shape process has rarely proven to be economically feasible for it. Contamination that degrades fatigue performance has limited utilization of titanium powder metal processing to nonrotating parts. Even so, the smooth-bar, axial fatigue properties of powder metallurgy Ti-6Al-4V products are superior to those of cast Ti-6Al-4V.[1] Consequently, there is currently a high level of effort in support of the powder metallurgical approach to net and near net shapes. On the other hand, there is a high level of interest in replacing forged and machined titanium impellers and rotors in engines with net shape, titanium castings because of the very significant cost savings projected. However, designers are not likely to accept cast titanium components if there is loss of performance with respect to forged Ti-6Al-4V. Forged steel impellers also are candidates for replacement by cast titanium; however, the motivation here is for cost effective improvement in performance. The casting approach has focused on titanium alloys of greater strength than Ti-6Al-4V. The problem that has been encountered in the casting approach isthat the most promising commercial titanium alloy from the standpoint of structural performance, Ti-6Al-2Sn-4Zr-6Mo, has welding difficulties that have not been resolved. Weld repair capability is necessary for casting to be economically feasible. The Transage alloys are a new type of martensitic, high hardenability titanium alloy.[2] In wrought form they have been demonstrated to have excellent weldability[3] and exceptional resistance to fatigue and fracture.[4] Cast-to-size bars of Transage 175 alloy were hot isostatically processed (HIP) to close any porosity, heat-treated, and evaluated by tension testing from 76 to 800°F (24 to 427°C) and by strain- or load-controlled axial fatigue testing at temperatures of 250 and 500°F (121 and 260°C). The results of these evaluations are the subject of this paper.

## Test Materials and Methods

The melting stock was prepared by double consumable electrode arc melting by TIMET, Division of Titanium Metals Corporation of America, Henderson, Nevada. Grade ML-115 titanium was used. The ingot was approximately 500 lb (230 kg) in size. Wax patterns for cast-to-size tension test specimen (CTS) bars were supplied by Detroit Diesel Allison, Division of General Motors, Indianapolis, Indiana. Bars of T175 were statically investment cast by Precision Castparts Corporation, Portland, Oregon. Bars were HIP by Industrial Materials Technology, Andover, Massachusetts. Conditions were 1500°F (815°C), 2 h, and 15 ksi (103 MPa). Since the particular HIP facility used did not have a rapid (inert gas) cool capability, the bars were solution heat-treated at 1500°F (815°C) prior to aging in order to simulate the cooling rate that would be expected in practice in a HIP facility with a rapid cool capability. Two batches of bars were cast for evaluation. The first batch, consisting of 43 bars, was given the heat treatment: 1500°F (815°C), 1 h, AC; 1000°F (538°C), 24 h, AC. The second batch, consisting of 33 bars, was given the heat treatment: 1500°F (815°C), 2 h, AC; 1075°F (579°C), 2 h, AC. The aging treatment was changed

Presented as Paper 81-0535 at the AIAA/ASME/ASCE/AHS 22nd Structures, Structural Dynamics and Materials Conference, Atlanta, Ga., April 6-8, 1981; submitted April 8, 1981; revision received March 11, 1982. 

*Consulting Engineer, Missiles Systems Division. Member AIAA.
†Metallurgical Development Manager.

for the second batch for two reasons. The temperature was changed because the bars of the first batch were closely grouped in a basket for solution heat treatment and were air-cooled that way. On the other hand, each of the bars of the second batch was cooled on refractory brick separated one from another. As a result, bars of the second batch cooled more rapidly.

Using instrumented specimens, the average cooling rate of the second batch was determined to be 450°F/min (4.2°C/s) between 1500 and 600°F (815 and 315°C). Similarly, the cooling rate was determined for a very slowly cooled bar. After aging at 1100°F (593°C) for 2 h, yield strengths of the bars were determined. The yield strength was found to increase with increasing cooling rate from solution heat treatment. By means of a correlation between the cooling rate from solution heat treatment, the aging temperature, and the yield strength, 1075°F (579°C) was selected as the aging temperature for the second batch of bars to produce approximately the same yield strength as exhibited by the first batch, i.e., 160 ksi (1103 MPa).[5] For a cooling rate of 450°F/min (4.2°C/s) from the HIP or solution heat treatment, tension test properties were found to be the same whether aging time at a given temperature was 2 or 24 h.[6] Therefore the aging time was shortened from 24 to 2 h in order to minimize oxygen contamination for aging in air. In production, it is expected that forced inert gas cooling following the HIP operation would serve as solution heat treatment. Being able to perform the final aging treatment in air would be economically advantageous. Shortening the aging time has the incidental benefits of increasing furnace productivity and conserving energy. Tension and low-cycle fatigue (LCF) tests were done by Mar-Test, Inc., and HCF tests were done by Metcut Associates, Inc., both of Cincinnati, Ohio. Test specimens were machined all over. All fatigue tests were axial. The LCF tests were strain-controlled and done at a frequency of 0.33 Hz. Smooth-bar specimens, $K_t = 1$, were tested at 250 and 500°F (121 and 260°C) for $R = 0$, $A = 1.0$. The HCF tests were load-controlled and done at a frequency of 60 Hz. Smooth-bar, $K_t = 1$, and notched-bar [60-deg notch with a 0.0085±0.0005-in. (0.22±0.01-mm) radius], $K_t = 3$, specimens were tested at 250°F.

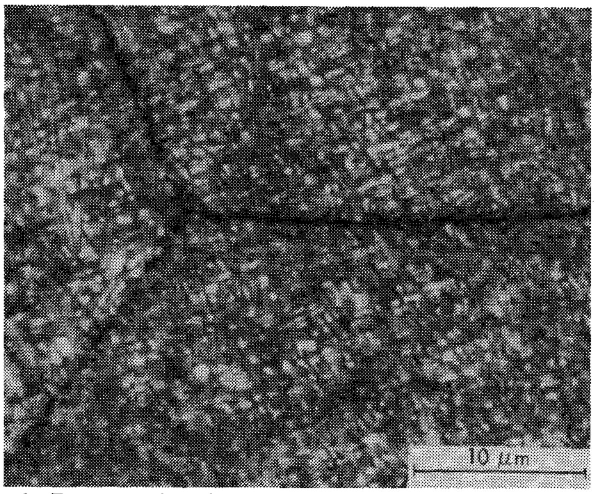


**Fig. 1 Representative microstructure of cast plus HIP, age-hardened Transage 175 alloy, 3000 ×.**

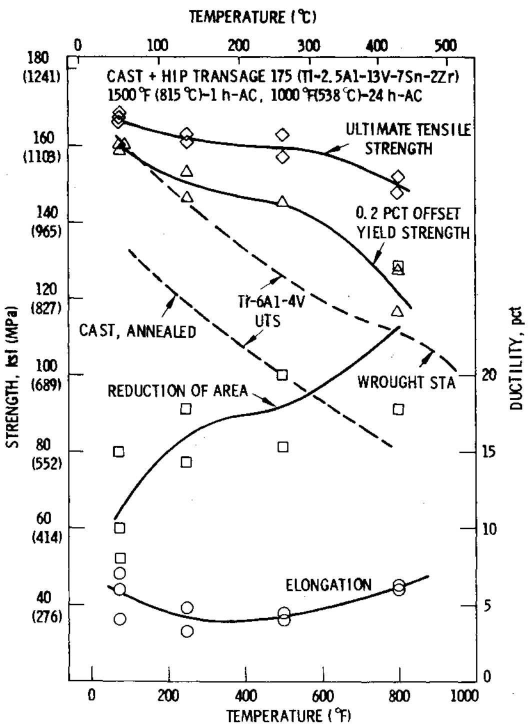


**Fig. 2 Tension test properties of cast plus HIP Transage 175 vs temperature compared with Ti-6Al-4V.**

## Results and Discussion

### Tension Test Results

A typical microstructure of the bars in the fully heat-treated condition is presented in Fig. 1. Note the exceptional fineness of the tempered martensite microstructure.

Tension test properties of the bars are given in Table 1. Tension test properties as a function of temperature are shown in Fig. 2. Ultimate tensile strength data for STA bar[7] and annealed cast[8] Ti-6Al-4V alloy are included for comparison. [For the most part, two considerations argue against the use of the solution heat-treated and aged condition of Ti-6Al-4V for castings. First, water quenching from a temperature of 1600°F (870°C), or higher, is required. Thin sections of complex geometry, e.g., impeller vanes or rotor blades, would suffer unacceptable distortion. Second, Ti-6Al-4V has such shallow hardenability that no significant strength advantage results when the casting section thickness exceeds 1/2 in. (12 mm).] Note that the yield strength of cast T175

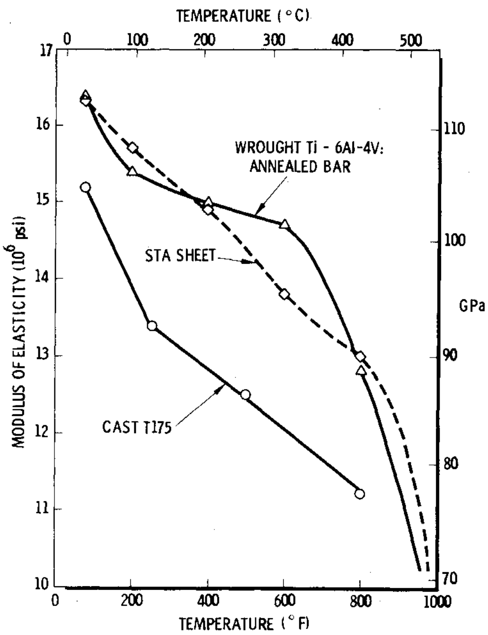


**Fig. 3 Modulus of elasticity of cast plus HIP Transage 175 vs temperature compared with Ti-6Al-4V.**

**Table 1 Tension test properties of cast plus hot isostatically processed bars of Transage 175 alloy (Ti-2.5A1-13V-7Sn-2Zr)[a]**

| Test temperature, °F(°C) | Yield strength 0.2% offset, ksi (MPa) | Ultimate strength, ksi (MPa) | Elongation, % | *RA*, % |
|---|---|---|---|---|
| First batch: heat treatment— 1500°F (815°C),1h,AC: 1000°F (538°C), 24 h, AC | | | | |
| 76 (24) | 160 (1103) | 167 (1151) | 6 | 11 |
| 250 (121) | 150 (1031) | 162 (1114) | 4 | 16 |
| 500 (260) | 145 (999) | 160 (1100) | 4 | 18 |
| 800 (427) | 122 (841) | 149 (1026) | 6 | 23 |
| Second batch: heat treatment— 1500°F (815°C), 1 h, AC; 1075°F (579°C), 2 h, AC | | | | |
| 76 (24) | 163 (1124) | 176(1213) | 3 | 10 |

[a] Data are averages for two specimens except for three first batch specimens at 76°F (24°C) and one second batch specimen at 76°F.

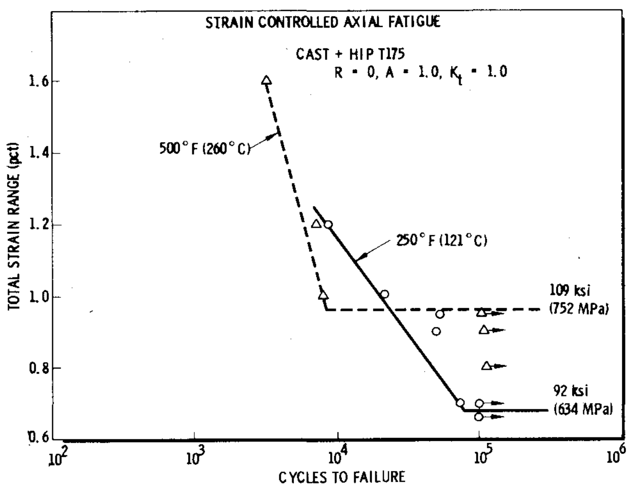


**Fig. 4 Strain-controlled, smooth-bar, low-cycle fatigue curves for cast plus HIP Transage 175.**

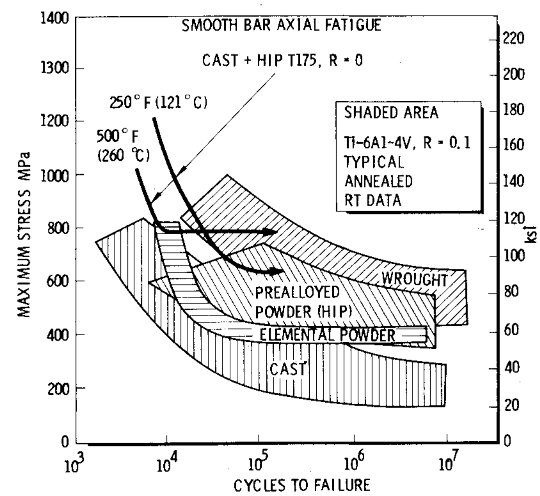


**Fig. 5 Comparison of fatigue curves for cast plus HIP Transage 175 with Ti-Al-4V in various product forms.**

exceeds the ultimate strength of STA Ti-6Al-4V at temperatures from 200 to at least 800°F (90 to 430°C).

The modulus of elasticity of cast T175 vs temperature is compared with Ti-6Al-4V in Fig. 3.[9] The data reported for cast T175 are averages determined from tensile test data and determinations made in support of the strain-controlled fatigue tests reported below.

### Fatigue Test Results

Results of the strain-controlled, axial LCF tests are presented in Fig. 4. A surprising result of the tests was that the $10^5$-cycle runout stress at 500°F (260°C) was 18% higher than that at 250°F (121°C). No explanation is offered for this finding. The test result is contrary to published results for other titanium alloys, including Ti-6Al-4V. However, it should be noted that the 500°F data represent the second batch of Transage 175 bars. (See the above discussion regarding the effects of the cooling rate from solution heat treatment on the aging response of the two batches of bars.) Creep was not a factor in the fatigue. The largest amount of plastic strain measured on a $10^5$-cycle runout specimen after test termination was 0.015%.

Pseudostress values corresponding to the strain-controlled loads are plotted in Fig. 5, together with generalized room temperature results for Ti-6Al-4V in various product forms. The Ti-6Al-4V data are from the work of Froes et al.[1] Cast T175 appears to offer considerably more promise for durability applications than powder metallurgy Ti-6Al-4V, assuming that its fatigue strength at room temperature is at least as high as it is at 250°F (121°C). (Ti-6Al-4V and other alpha-beta titanium alloys for which data are reported in the literature have progressively lower fatigue strength with increasing temperature from room temperature.)

The results of the HCF tests are presented in Fig. 6. In both the smooth and notched specimen conditions, cast Transage 175 shows impressive results for completely reserved stress, axial HCF at 250°F. Unfortunately, comparable data for Ti-6A1-4V were not available in the open literature.

The closed symbols in Fig. 6 represent $10^7$-cycles runout specimens that were retested at higher stresses. All three such specimens had a longer life than would have been expected from curves drawn through the data for virgin specimens. From this experience, two tentative conclusions may be drawn. First, fatigue strain hardening occurred at 250°F (121°C). Second, cast Transage 175, at least in the thin section, has a true endurance limit, consistent with experience with wrought Transage alloys.[3,4] Results for all of the fatigue testing are summarized in Table 2.

**Table 2 Summary of fatigue performance of cast plus HIP Transage 175**

| Test temperature, | | Stress ratio | | Transage 175 CTS bars total stress range | |
|---|---|---|---|---|---|
| | | | | $10^5$ cycles, | $10^7$ cycles, |
| °F (°C) | $K_t$ | $A$ | $R$ | ksi (MPa) | ksi (MPa) |
| 250 (121) | 1.0 | 1.0 | 0 | 92 (634) | ... |
| 599 (260) | 1.0 | 1.0 | 0 | 109 (752) | ... |
| 250 (121) | 1.0 | ∞ | −1.0 | ... | 110 (758) |
| 250 (121) | 3 | ∞ | −1.0 | ... | 55 (379) |

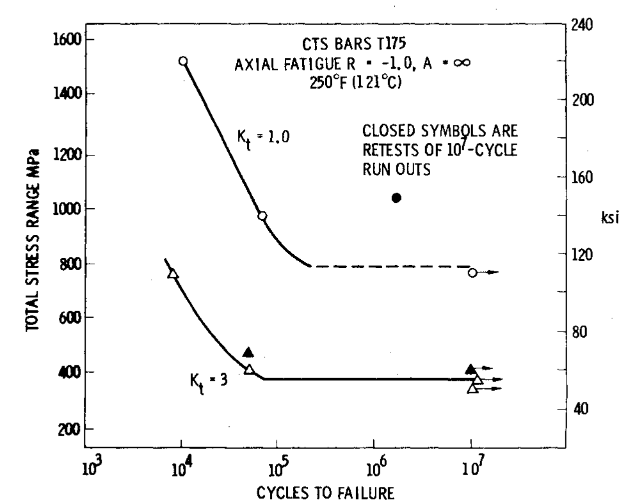


**Fig. 6 Smooth- and notched-bar, high-cycle fatigue curves for cast plus HIP Transage 175.**

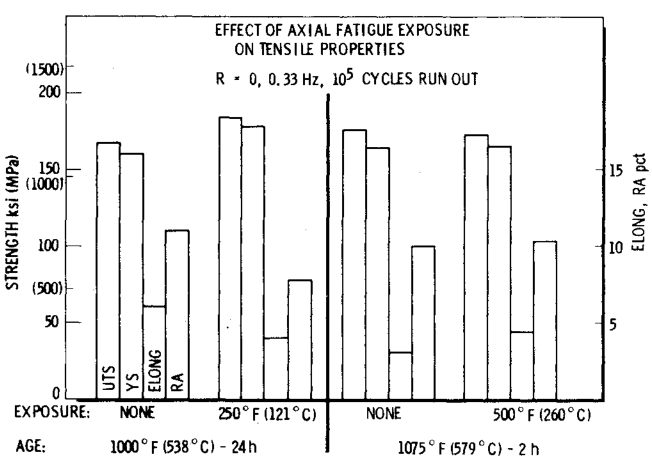


**Fig. 7 Stability of cast Transage 175 at elevated temperature fatigue exposure.**

#### Stability

The stability of cast T175 at elevated temperature fatigue exposure was evaluated by tension testing at room temperature the two 250°F (121°C) and the three 500°F (260°C) $10^5$-cycles runout specimens. Average values of the tensile properties are compared with those of unexposed specimens in Fig. 7. The two 250°F runout specimens had an average increase in yield strength of 18 ksi (124 MPa) compared to baseline properties, and an average elongation decrease from 6 to 4%. The three 500°F runout specimens showed no significant changes in properties.

#### Weldability

Regarding the weldability of cast T175, a 10-in.-diam (250-mm-diam) impeller was cast in T175 by Precision Castparts for Detroit Diesel Allison, Detroit, Michigan. The casting was successfully repaired by welding.

## Summary and Conclusions

Cast plus HIP Transage 175 alloy has been demonstrated to have excellent short-time strength and excellent fatigue strength under a variety of loading conditions as summarized in Table 2. Castings of the alloy thus qualify as prime candidates to reduce to cost of titanium components in airframes and some engines by their substitution for titanium forgings. For some conditions of fatigue loading, improvement in performance may be possible as well. Cast plus HIP Transage 175 also offers promise for cost effective improvement in structural efficiency by its substitution for steel forgings.

## References

[1] Froes, F.H., Eylon, D., Eichelman, G.E., and Burte, H.M., "Developments in Titanium Powder Metallurgy," *Journal of Metals* Vol. 32, Feb. 1980, pp. 47-54.

[2] Crossley, F.A. and Lindberg, R.W., "Microstructural Analysis of a High Strength Martensite-Beta Titanium Alloy," *Proceedings of the Second International Conference on the Strength of Metals and Alloys*, Asilomar, Calif., ASM, 1970, Vol. III, pp. 841-845.

[3] Crossley, F.A. and Van Orden, J.M., "A New Titanium Alloy for Forms and Weldments," *Metals Engineering Quarterly,* Vol. 13, May 1973, pp. 55-61; see also *Source Book on Materials Selection*, American Society for Metals, Metals Park, Ohio, 1977, Vol. II, pp. 170-176.

[4] Crossley, F.A. and Jeal, R.H., "Fatigue and Fracture Behavior of the High Hardenability 'Transage' Titanium Alloys," *Proceedings of the AIAA 21st Structures, Structural Dynamics, and Materials Conference,* Part 2, New York, N.Y., 1980, pp. 572-577; see also *Journal of Aircraft,* Vol. 18, Aug. 1981, pp. 683-686.

[5] Crossley, F.A. and Barice, W.J., "Mechanical Properties of Two Cast and Hot Isostatically Processed Martensitic Transage Titanium Alloys," *Journal of Metals,* Vol. 33 , Feb. 1981, pp. 26-32.

[6] Crossley, F.A. and Barice, W.J., "Influence of Hot Isostatic Processing and Heat Treatment Variables on the Tensile Properties of Cast Transage 175 Alloy, Ti-2.5Al-13V-7Sn-2Zr," *Materials Overview for 1982,* Vol. 27, pp. 667-678, 27th National SAMPE Symposium and Exposition, May 1982, San Diego, Calif.

[7] "Properties of Ti-6Al-4V," TIMET, Division of Titanium Metals Corporation of America, Pittsburgh, Pa., revised Feb. 1965, p. 23.

[8] "Titanium Castings Today," MCIC-73-16, Battelle Columbus Laboratories, Columbus, Ohio, Dec. 1973, p. 17.

[9] "Properties of Ti-6Al-4V," TIMET, Division of Titanium Metals Corporation of America, Pittsburgh, Pa., revised Feb. 1965, pp. 21, 25.