EFFECT OF SHOT PEENING ON FATIGUE PERFORMANCE OF TWO TITANIUM ALLOYS

H. Bae, B. Flinn, M. Ramulu, G. Weber* and H. Diep*

University of Washington, Seattle WA, USA

* The Boeing Company, Seattle WA, USA

ABSTRACT

The aerospace industry has taken interest in Ti 5Al-5Mo-5V-3Cr (Ti5553) for use in fatigue critical applications. To more fully understand the underlying fatigue mechanisms, Ti5553 was compared to the baseline alloy Ti 6Al-4V (Ti64) under cyclic loading conditions. This paper addresses the performance of as-machined and as-peened smooth round fatigue specimens of both alloys, including fatigue data, surface roughness, fractography and metallography. Surface topography of as-machined samples showed higher roughness values for Ti-5553 than Ti64, and the Ti5553 exhibited higher S-N plot scatter than Ti64. However, consistent fatigue behavior was demonstrated for the as-peened specimens. Fracture surfaces indicated standard fatigue and ductile failure modes. Shot peening process increased fatigue life of Ti5553 and Ti64 with increasing surface hardening and surface roughness.

INTRODUCTION

In the development of high strength custom alloys, fatigue life has become a limiting factor in the service life of parts [1,2]. Predicting and mitigating the mechanisms of fatigue not only enables operating cost reductions by decreasing the structural weight of airframes but also decreases the in-service costs of maintaining complex structures. Several processes, such as shot peening, have been developed to induce a residual stress in the surface of a part to enhance the fatigue life. Ti64 has been the standard "work horse" in aerospace industry, while Ti5553 has been found to exhibit excellent hardenability combined with superior strength, high fracture toughness and excellent high cycle fatigue behavior properties compared to Ti64 [3-7]. As a result of these properties, Ti5553 forgings may have a potential use in highly loaded parts such as flap tracks and pylon or landing gear applications [7,8].

The aerospace industry is interested in using Ti5553 in fatigue-critical aerospace applications, which demands the study of fatigue performance. The purpose of this study is to generate the baseline fatigue data and compare Ti5553 to the better-known alloy Ti64 using smooth fatigue specimens, with a focus on the 10^5-10^6 cycles region. Shot peened specimens were also fatigue tested and compared to the baseline data. The fracture surfaces were studied with scanning electron microscopy.

EXPERIMENTAL PROCEDURE

Two titanium alloys namely Ti5553 and Ti64 were investigated in this study. Chemical composition of these two alloys is given in Table 1. Typical mechanical properties are given in Table 2.

Cylindrical test specimens (7 mm (0.275") gauge diameter) were machined from forged plates of both Ti64 and Ti5553, and fatigue tested in the as-machined and shot peened conditions. Shot peening for the cylindrical titanium fatigue specimen

Table 1 Weight percentage of components in Ti64 and Ti5553 Alloys [4]

	Al	V	Mo	Cr	Fe	O	C	Zr
Ti64 [1]	6	4			Max 0.25	Max 0.2		
Ti5553 [2]	4.4-5.7	4.0-5.5	4.0-5.5	2.5-3.5	0.3-0.5	Max 0.18	Max 0.1	Max 0.3

Table 2 Comparison of Ti64 and Ti5553 Material Properties [1,4]

Property	ASM[1] Ti-6Al-4V	Ti-5Al-5V-5Mo-3Cr[1,2]
Heat Treat	Mill Annealed	Beta Annealed Slow Cooling Aged
Ultimate Tensile Strength (MPa)	950	1236
Yield Strength (MPa)	880	1174
Elongation (%)	14	13
Young’s Modulus, E, (GPa)	113.8	115
Fracture Toughness, KIC, (MPam$^{1/2}$)	75	70
Density (Kg/m^3)	4430	4650

was 0.1524 mmA-0.28mmA (0.006A-0.011A) using cut wire CW32 steel shot with 100% coverage. A 100KN computer-controlled material test system (MTS) servhydraulic-testing machine was used for tension-tension fatigue experiments. The load ratio (R=Smin/Smax) was kept at 0.1 under a load-control mode, with a sinusoidal waveform at a frequency of 15 Hz.

Surface roughness measurements were taken on all the specimens prior to testing using a contact surface profilometer, and surface profiles were recorded with a cut-off length of 0.8mm. Selected specimens of interest were sectioned for fractography as well as metallography using light optical microscopy as well as scanning electron microscopy (SEM) to evaluate the fracture surface characteristics.

RESULTS AND DISCUSSION

Figure 1 shows the typical microstructures of Ti64 and Ti5553 at two different magnifications respectively. The microstructure of Ti64 is well developed, with an even distribution of alpha structures within the larger beta grains. The Ti5553 microstructure shows fully recrystalized beta grains with alpha present on residual grain boundaries. Grains were well equiaxed across longitudinal sections and cross sections of the specimens, as well as consistent in size and shape across specimens.

Figure 2 and Figure 3 show the SEM micrographs of the as-machined and shot peened surface of the two titanium alloys Ti64 and Ti5553 test samples respectively. Note the clear machining feed marks on the as machined specimens of the both alloys. The surface quality of the Ti64 is consistent and smooth and shows very little pitting – which is indicative of poor cutting – in contrast to the machining damage and surface defects seen on Ti5553. However, the shot peening process clearly suppressed and/or modified all the feed marks and generated a homogeneous surface.

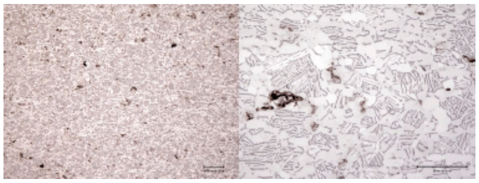
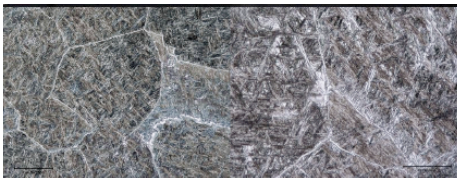
	
Ti6-4 Cross section at 100x and 500x	Ti5553 Cross section 200x and 500x

Figure 1 Microstructures of two specimens

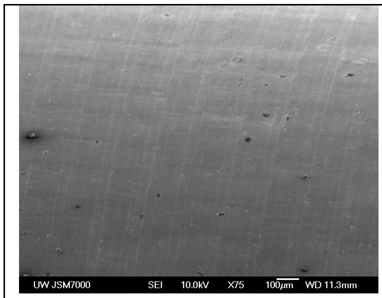
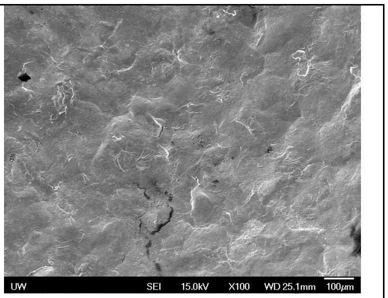
	
As-Machined	As-Shot peened

Figure 2 As-machined surface and shot peening surfaces of Ti64

Figure 4 shows the surface roughness values of two specimens. For the as-machined specimens, the R_a value of Ti5553 is 1.6 times higher than that of Ti64. This indicates that the machining process used for the newer and higher strength Ti-5553 alloy was less refined. However, in case of shot peened specimens, the R_a values of two specimens are similar. Surface roughness ratios of the shot peened specimens compared to the machined specimens are 3.0 for Ti64 and 1.8 for Ti5553.

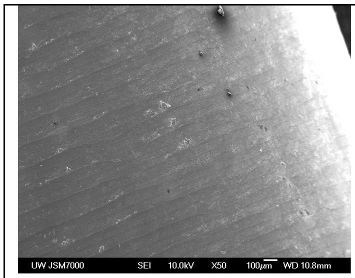
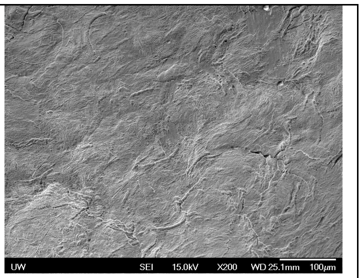
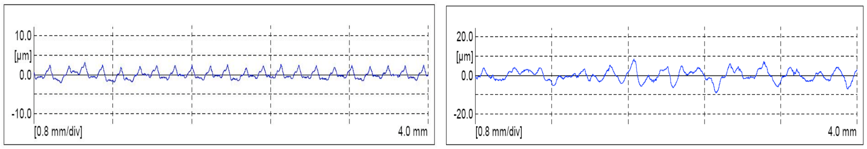
	
As-Machined	As-Shot peened

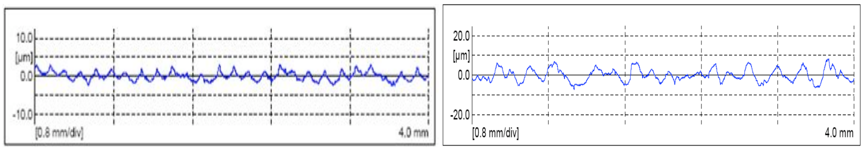
Figure 3 As-machined surface and shot peening surfaces of Ti5553

The micro hardness values for shot peened specimens for the two alloys normalized against the center, unmodified material microhardness measurement are shown in Figure 5. Shot peening caused surface hardening of about 10-16% and 18-24% higher than as-machined surface hardness in Ti64 and Ti5553 respectively. Note the depth of hardening was also higher in Ti5553 alloy.



(a) As-Machined
(Ra=0.82,Rt=4.85,Rz=4.31μm)

(b)As-Peened
(Ra=2.449,Rt=16.8,Rz=12.4μm)



(c) As-Machined
(Ra=1.32,Rt=7.69, Rz=6.77μm)

(d) As-Peened
(Ra=2.407,Rt=16.43,Rz=12.4μm)

Figure 4 Surface roughness profiles of Ti-64 (a,b) &Ti -5553 (c,d)

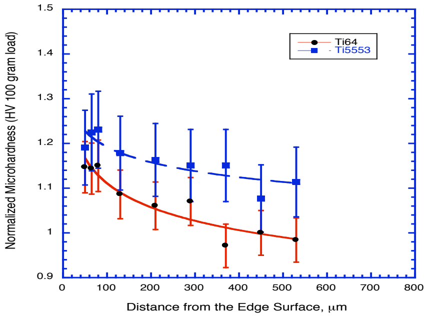
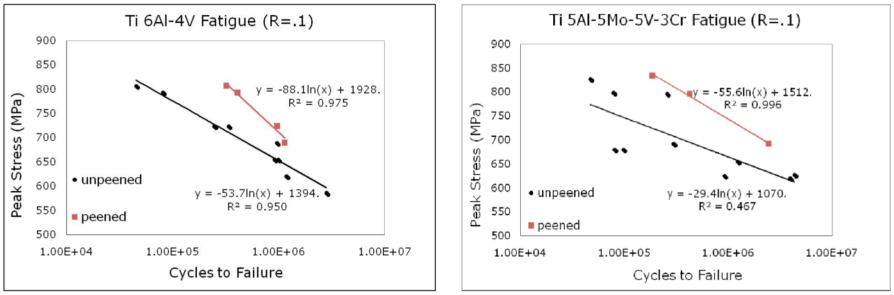


Figure 5 Normalized Hardness vs. Distance from Edge of Ti64 (HVbase 100g= 313) and T5553 (HVbase 100g= 321)



(a)

(b)

Figure 6 S-N curves of Ti64 and Ti5553

Figure 6 shows the fatigue performance in terms of S-N curve of as-machined and shot peened titanium specimens. Fatigue behavior of as-machined Ti5553 did not show nearly the same level of consistency as that of Ti64. The S-N curve shows scatter between as-machined specimens of Ti5553 run under the same conditions is high as evidenced by an R^2 value of .46. This is attributable to the higher surface roughness of the as-machined Ti5553 specimens. The effect of shot peening in improvement in fatigue properties of Ti64 and Ti5553 can be seen clearly in both Figures 6a and 6b. Surface hardening (Figure 5) and roughness (Figure 4) are factors which undoubetdly influence the fatigue life [8]. Surface hardening of Ti5553 was much higher than that of Ti64 (Figure 5)

Typical fracture surfaces of the fatigued specimens are shown in Figure 7. The fatigue cracks intiated on the surface for all the specimens tested in as-machined condition for both alloys. As expected, in all shot peened specimens, fatigue cracks initiated in subsurface regions, as shown in figure 7. Figure 7 also illustrates the distinct crack initiating regions and final fracture region regardless of surface condition. It is important to mention here that fractographic study of the Ti5553 revealed a region of both dimples and striations suggesting mixed fracture modes and further investigation on this behavior is in progress and will be communicated in the future.

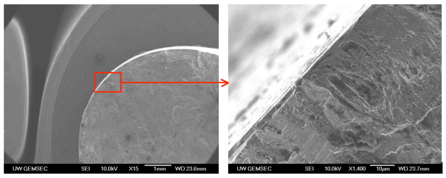
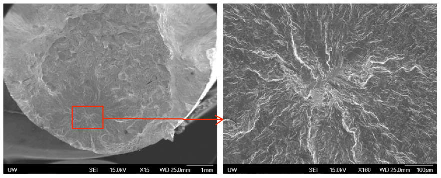
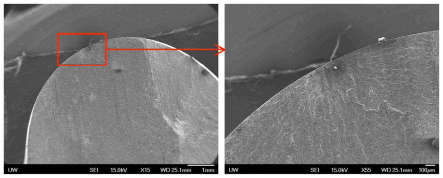
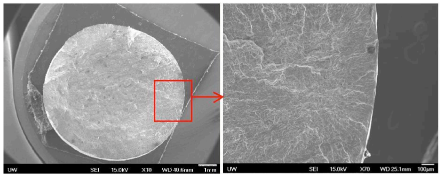
	
As-Machined Ti5553	As-Shot peened Ti5553
	
As-Machined Ti64	As-Shot peened Ti64

Figure 7 SEM Micrographs of fractured surface fatigue origin of as-machined and shot peened specimens fatigued at R=0.1.

SUMMARY AND CONCLUSIONS

Experimental investigation of the high cycle fatigue performance of two titanium alloys, namely, Ti5553 and Ti64 was conducted. Shot peening increased surface hardness and surface roughness regardless of alloy material. Fatigue performance was clearly enhanced after shot peening of Ti64 and Ti5553 in comparison to the as-machined condition. The fatigue life of Ti5553 was improved significantly by shot peening process and had better performance than Ti64. Further research should test fully polished specimens in an attempt to eliminate surface roughness differences between two alloy samples, allowing one to determine if differences in fatigue life are driven by the initiation of the crack or by the microstructure once the crack has been initiated.

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