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Coverage and Peening Angle Effects in Shot Peening on HCF Performance of Ti-6Al-4V

Jochen P. Fuhr[a]*, Mahmoud Basha[b], Manfred Wollmann[b], Lothar Wagner[b]

[a]*Curtiss-Wright Surface Technologies/Metal Improvement Company, 58739 Wickede, Germany*

[b]*Institute of Materials Science and Engineering, TU Clausthal, 38678 Clausthal-Zellerfeld, Germany*

Abstract

Shot peening of titanium alloys is known to enhance the HCF strength by inducing in near-surface regions residual compressive stresses which can drastically retard the growth rates of surface cracks. In addition, the induced high dislocation densities may increase the resistance to fatigue crack initiation while the typically accompanied high surface roughness has the opposite effect.

The present work aimed at studying the effect of coverage and peening angle effects in shot peening on fatigue crack initiation and micro-crack growth on Ti-6Al-4V.

The coverage was varied to a wide extent ranging from 20 % to 1200 % and the peening angle from 90 to 30 degrees. Fatigue life of shot peened rotating bending hour-glass shaped and flat bending fatigue specimens was studied and compared to an electrolytically polished reference.

The results indicate that low (20%) coverage peening leads to a loss in HCF strength, presumably caused by insufficient residual compressive stress fields which cannot compensate the early crack initiation caused by the high roughness. In contrast, full (100 %) up to a high (1200 %) coverage was found to result in a marked increase in HCF strength.

The variation of peening angles resulted in a significant beneficial effect on the fatigue strength of the flat bending fatigue samples in direction to increasingly flat angles and high coverages (1200 %) at constant Almen intensities of 0,20 mmA. Beside the deeper compressive stress layer at flat impact angles especially the increased dislocation density and the creation of a material texture orientated 90 degrees to the cracking direction seems to be responsible for the increased fatigue strength.

These results are even more interesting as those peened surfaces resulted in the highest roughness values and a topography with a starting waviness on the surface.

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Keywords: Ti-6Al-4V; HCF Fatigue; Coverage; Shot Peening; Roughness; Shot Hardness; Impact Angle

1. Introduction

The α+β Ti-6Al-4V is widely used in aerospace industry, especially aero engine components like blades, disks, drums or state of the art blisks. Shot peening is a common and broadly used post-surface treatment that increases the overall fatigue performance and/or eliminates the detrimental effects or scattering caused by the manufacturing processes. Shot peening induces compressive residual stresses in near-surface regions that can drastically retard the growth rates of fatigue cracks [1]. In addition, the induced high dislocation densities may increase the resistance to fatigue crack initiation while the typically accompanied high surface roughness can have the opposite effect.

* Corresponding author. Tel.: +49 2377 785380; fax: +49 2377 7853811.
E-mail address: jochen.fuhr@cwst.com

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Fatigue performance of metallic parts can be markedly influenced by coverage degree in shot peening (SP) [2-3], [4]. Low coverage degrees (<< 100 %) led to fatigue lives even lower than in the untreated electropolished reference condition [5]. These results were explained by residual compressive stresses being not fully developed at low coverage degrees and, therefore, were not able to compensate the early fatigue crack initiation caused by the highly induced surface roughness from the shot peening process. The fully developed residual compressive stresses in minimum 100% coverage were then seen to drastically reduce micro-crack growth by which the early fatigue crack initiation was much overcompensated leading to marked enhancements in the overall fatigue life.
Present work aims investigating the effects either of a realistic coverage of 20, 100 and 1200 % and different impact angles of 90, 60, 45 and 30 degrees that can occur on Ti-6Al-4V aerospace parts within shot peening in new manufacturing and/or following maintenance, repair and overhaul (MRO) treatments applied during the lifetime of such a component.

2. Material & Experimental Metods

Ti-6Al-4V was received as cylindrical rods Ø 12.7 mm. The used material was Grade 5 (3.7165) fulfilling the material specifications ASME SB348, ASTM B348, UNS R56400. The chemical composition and tensile properties are listed in Tables 1 and 2.

Table 1: Chemical composition

Element	Al	Cu	Fe	Mo	Ni
wt %	6.68	<0.005	0.1581	<0.01	0.0115
Element	Si	Sn	V	Zr	Ti
wt %	0.0115	<0.01	4.114	<0.003	89.0

Micrographs of the α+β Ti-6Al-4V are showing typical globular microstructure with no marked texture (Figure 1). The tensile properties are listed in Table 2.

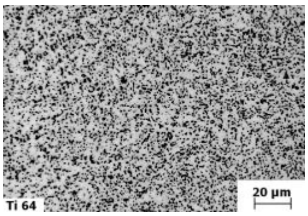

Fig. 1: Micrograph of the globular microstructure

Table 2: Tensile properties

Rp0.2 [MPa]	Rm [MPa]	A [%]	E [GPa]
990	1035	17.4	101

For fatigue testing the 20, 100 and 1200 % coverage, hour-glass shaped specimens (6 mm minimum cross section diameter) were machined (Figure 2(a)). Electrolytically polished (EP) and mechanically polished (MP) conditions were used as references to which the shot peening at various coverage degrees were compared. EP was done to remove about 100 µm from the as-machined surface to exclude any machining effects that could have masked the results. During MP, a surface layer of about 50 µm was removed from the as-machined surface resulting in the same very smooth surface condition as observed in EP condition.
Fatigue tests were performed in load controlled rotating beam loading (R = -1) in air at a frequency of 50 s-1.

For the testing of the 90, 60, 45 and 30 degrees impact angle at 100 and 1200 % coverage flat shaped fatigue samples (Figure 2(b)) have been machined and shot peened. The fatigue testing was carried out in a load controlled fatigue machine where the force on the flat specimen is applied by a cam and linkage (R = -1) in air at a frequency of 8 s^{-1}.
All Specimens were considered as run-outs after 10^7 cycles.