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Application of mechanical surface finishing processes for roughness reduction and fatigue improvement of additively manufactured Ti-6Al-4V parts

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Abstract

Currently, additively manufactured (AM) parts have a high initial surface roughness after the manufacturing process, which can be a limitation for application in highly stressed and cyclically loaded areas. In the present study, Ti-6Al-4V samples were manufactured by laser beam melting, annealed and hot isostatically pressed afterwards. They showed an initial surface roughness of $R_a = 17.9$ µm depending on their build direction (45°). Subsequently, four different mechanical surface finishing processes were applied separately on plates and fatigue coupons in order to reduce the surface roughness: Milling, blasting, vibratory grinding and a micro machining process. The effectiveness of each treatment is evaluated with respect to the surface topography, as well as the fatigue properties based on axial fatigue tests performed in accordance to DIN EN 6072. The initial roughness could often be reduced to values $R_a < 1$ µm. The roughness decrease led to a substantial increase in the fatigue performance from initially 300 MPa to a maximum of 775 MPa (after 3×10^7 cycles).

Key words: high-cycle fatigue, additive manufacturing, titanium, Ti-6Al-4V, laser beam, surface treatments, milling, micro machining process, vibratory grinding, blasting, surface roughness

1. Introduction

Nowadays, titanium alloys and especially Ti-6Al-4V (Ti64) are of increasing importance for the aerospace industry [1]. Due to its high strength, high resistance to corrosion and its low density, this material can be used to replace heavier alloys in order to save weight or create new functionalities [2-4]. Ti64 can also be processed by additive manufacturing (AM) technologies, which offers the opportunity to significantly reduce both, the amount of raw material needed and the weight of a component. This is possible due to the build-up of highly complex net-shaped parts almost without any additional tooling. Processing Ti64 by additive manufacturing, the raw material is often either powder or wire based. The parts are realized directly out of a computer-aided design (CAD) model, which is built up layer by layer in incremental steps. During the additive manufacturing process the raw material is selectively molten by an energy source (e.g. laser or electron beam) within each layer. Many ongoing studies focus on the optimization of the AM process or the post-treatment of the parts. In addition to heat treatment procedures, surface finishing of the as-built parts is mandatory after the manufacturing process for many applications [5-7]. After a powder bed process, as-built parts face a high initial surface roughness, which is caused by powder particles sticking to the molten surface contour during manufacturing. This causes heterogeneous and non-reproducible surface morphologies [5, 8]. Since this roughness might cause additional notch effects and trigger crack initiation, it also has a negative impact on the fatigue performance [6, 9-15]. Therefore, the roughness has to be decreased